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The utility of well-being and physical performance assessments in managing the development of elite youth football players

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Ph.D

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Abstract

Training stress in the absence of adequate recovery has been associated with a decrease in well-being and performance. Thus, there is potential for the high training and competition loads that elite English youth football players experience to have a negative effect on well-being and performance. The aim of the thesis was to assess the utility of well-being and physical performance assessments in managing the development of elite English youth football players. The first study (Chapter 4) examined the sensitivity of a subjective well-being questionnaire (WQ; developed ‘in-house’ by sport science practitioners at a category two academy and only taking < 30 s to complete), by comparing the player’s next day responses between two acute training bouts of varied duration; 15 mins (low load) compared to 90 mins (high load) high intensity intermittent exercise (Loughborough intermittent shuttle test, LIST). WQ items showed small to large deteriorations following the high load compared to low load (d=0.4-1.5, P=0.03-0.57). The ability of the WQ to differentiate between responses to high and low training loads indicated that this questionnaire could be used to detect training induced stress prior to training on a daily basis throughout the season. Other modes of monitoring assessment evaluated were either not sensitive to differentiate between high and low loads (countermovement jump; CMJ) or detected differences between high and low training load responses (HR indices) but lacked utility in detecting individual changes. The second study (Chapter 5) applied well-being and physical performance assessments to elite English youth football players during a high intensity, low volume pre-season training period. Trivial changes in perception of WQ items of sleep, recovery, appetite, fatigue, stress and muscle soreness were observed across weeks (P=0.35-0.93, η_p^2 =0.02-0.08) with no negative WQ responses evident. Internal training load was lower to a large extent in week 1 (P=<0.001, η_p^2 =0.54) yet no differences in internal training load were evident across weeks two, three,

four and five. Trivial to small associations (r=-0.21 to 0.19) between internal training load and WQ responses were observed. Small to moderate improvements in aerobic performance were evident post training in comparison with pre training (P<0.001-0.53, d= 0.33 – 0.94) with a large to moderate improvement in submaximal HR measures (P<0.001 – 0.09; η_P^2 = 0.34 - 0.74) observed across the training weeks. Trivial to moderate impairments in neuromuscular performance were evident post training in comparison with pre training (P<0.001 – 0.21; d= 0.17 – 1.00). Collectively, the preservation of well-being prior to each training session during a pre-season period and improvements in aspects of physical performance were indicative of a balance between stress and recovery. The third study (Chapter 6) examined player perceptions of well-being and physical performance across a season in Elite English youth football players. Increases in training exposure (P<0.05; η_P^2 =0.52) and moderate to large deteriorations in perceptions of well-being (motivation, sleep quality, recovery, appetite, fatigue, stress, muscle soreness P<0.05; η_P^2 =0.30-0.53) were evident as the season progressed. A large improvement in Yo-Yo intermittent recovery test performance (Yo-Yo IRT; P<0.05; η_P^2 =0.93) and a small to moderate impairment in neuromuscular performance (P>0.05; η_P^2 =0.18 - 0.48) was observed as the season progressed. These findings show an imbalance between stress and recovery in English elite youth football players even when players experienced lower training exposure than stipulated by the elite player performance plan (EPPP). In summary, this thesis highlights the potential utility of subjective well-being assessments to inform the management English elite youth football player development. Furthermore, it highlights the high training volumes that English elite youth players are exposed can potentially lead to an imbalance between stress and recovery.

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Dedication

To my daughter Phoebe Louise Noon.

Publications

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Table of Contents **Page**

List of Figures

List of tables

List of abbreviations

AAT	Arrowhead agility test
ATP	Adenosine Triphosphate
bTRIMP	Bannisters training impulse
CI	Confidence interval
CMJ	Countermovement jump
CV	Coefficient of variation
DALDA	Daily analysis of life demands for athletes
dRPE	Differential RPE
Edwards TRIMP	Edwards training impulse
EPPP	The Premier League's Elite player performance plan
FA	The English Football Association
FOR	Functional Overreaching
FP	Foundation phase
GLM ANOVA	General linear model analysis of variance
HIIT	High intensity interval training
HIMS	Heart rate interval monitoring assessment
HR	Heart rate
HR_{ex}	Exercising HR
HR_{max}	Heart rate maximum
HRR	Heart rate recovery
HR_{res}	Heart rate reserve
HR_{rest}	Resting heart rate
iTRIMP	Individualised training impulse

KPI	Key performance indicator
LIST	Loughborough intermittent shuttle test
Lucia TRIMP	Lucia training impulse
MAS	Maximal aerobic speed
mRPE	Muscular RPE
MTDS	Multicomponent measure of training distress
NFOR	Non-functional overreaching
OTS	Overtraining syndrome
PDP	Professional development phase
POMS	Profile of mood states
RESTQ-Sport	Recovery-stress questionnaire for sport
RPE	Rate of perceived exertion
rRPE	Respiratory RPE
S2	Speed at a fixed blood-lactate concentration of 2 $mmol \cdot l^{-1}$
S4	Speed at a fixed blood-lactate concentration of 4 $mmol \cdot l^{-1}$
sRPE	Session RPE
SSG	Small sided games
SPSS	Statistical Package for Social Science
SWC	Smallest worthwhile change
TE	Typical error
Team TRIMP	Team training impulse
TRIMP	Training impulse
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_2$ max	Maximal oxygen uptake

$\dot{V}O_2$ peak	Peak oxygen uptake
WQ	Well-being questionnaire
YDP	Youth development phase
Yo-Yo IRT1	Yo-Yo Intermittent recovery test level 1
Yo-Yo IRT2	Yo-Yo Intermittent recovery test level 2

CHAPTER 1

1.0 Introduction

Player well-being is regarded to be of the utmost importance to the development of elite youth football players (Brink et al., 2012). Each football club responsible for the development of youth players has a duty of care, managed by coaches and support staff, to ensure the well-being of players. Well-being is a multi-dimensional concept that encapsulates a range of physical and psychological constructs, including mood state (e.g. motivation), behaviour (e.g. sleep) and physical symptoms (e.g. muscle soreness; Saw et al., 2016). Stress, defined as a stimulus which imposes a negative biological and psychological response (Kentta and Hassmen, 1998), is accumulated from training and competition, relationships and environmental pressures and is a key determinant of player well-being (Meeusen et al., 2013). Recovery, defined as the process of restoration (Barnett, 2006) from these stressors, must be adequate to preserve well-being and maintain and / or improve performance during the training process (Meeuson et al., 2013). In the absence of adequate recovery, fatigue, defined as an inability to perform a task which was once achievable in a recent time frame (Halson, 2014; Thorpe et al., 2017), develops. This is often but not always associated with a decrease in well-being (Meeuson et al., 2013). Hence, the day to day management of the players' training process requires metrics which assess their individual well-being and performance.

The current youth development model set out by the Premier League stipulates that players in the professional development phase (PDP; U17-U21) must be exposed to a high number of training hours (12-14 h per week) that focus on players' technical and tactical development through deliberate practice (The Premier League, 2011). In addition, the development model states 'winning must matter' and an emphasis must be placed on training to win and performance. Although deliberate practice is considered an important aspect of skill acquisition, the prescription of large training stress, without adequate recovery, is likely to result in fatigue and contribute to reduced well-being (Meeusen et al., 2013). Hence, coaches face a unique challenge in managing player well-being and performance.

Football performance is multifaceted and dependent on the successful execution of a range of specific tasks which incorporate technical, tactical, psychological and physical components (Hughes et al., 2012). At any point, the reduced ability to perform football specific tasks is dependent on the prevailing level of stress accumulated and the relative combination of physical and mental factors determining it. However, the contribution of physical and mental factors in determining football performance is difficult to quantify (Meeuson et al., 2013; Saw et al., 2016). Furthermore, the evaluation of player performance is difficult given the multi-factorial demands of the game.

Effective training periodisation, which incorporates an appropriate training 'dose' or 'load', a resultant stress and adequate recovery, is required to optimise physical performance (Meeusen et al., 2013). An insufficient training dose may result in a reduction in physical fitness (Issurin, 2010). Additionally, an excessive dose may result in physical fatigue, which manifests as a result of a range of physiological and / or psychological mechanisms, which may or may not be associated with a reduction in well-being (Meeusen et al., 2013). In this thesis, the time course of physical recovery associated with physical fatigue will be differentiated between using the following terms: temporal fatigue; a transient decrement in physical performance lasting for a brief period during match play or training (Bradley et al., 2009). Acute physical fatigue; the transient decrement in physical performance that is present following a game or training that lasts hours, a day or several days (Meeuson et al., 2013; Nedelec et al., 2012). Functional overreaching (FOR); a decrease in physical performance lasting days or weeks where physical performance is recovered prior to the next training session or competitive fixture (Faude et al., 2014; Meeuson et al., 2013). Non-functional overreaching (NFOR); which in this thesis is defined as a decrease in physical performance which takes weeks or months to recover from or a transient decrement in physical performance present prior to a competitive fixture (Faude et al., 2014; Meeuson et al., 2013). Overtraining syndrome (OTS); a decrement in physical performance lasting months (Meeuson et al., 2013).

Clearly fatigue is a complex and multifaceted phenomenon (Noakes et al., 2005; St Clair Gibson and Noakes, 2004; Thorpe et al., 2017) and is more thoroughly discussed in detail in section 2. Establishing monitoring assessments which accurately quantify the dose and /or the resultant stress, due to training and competition, and are sensitive to the subsequent recovery process are necessary (Halson, 2014). Ideally these monitoring assessments are applied day to day and inform player management by allowing coaches to make informed choices with regard to effective training within the current stage of training periodisation.

The panacea of monitoring assessments would be an inexpensive, easy to administer method which indicates well-being and aspects of physical performance in a single term, yet also identifies how the combination of well-being and aspects of physical performance at any given time influence football performance (Saw et al., 2016). No such measure exists. However, various monitoring assessments, such as subjective questionnaires and physical performance tests, individually or collectively can give valuable information about the training and competition dose, the resultant stress and subsequent recovery. Without an understanding of the impact of the player's training and competition dose it is difficult to adjust subsequent training. Yet, a measure assessing the subsequent recovery of well-being and or physical performance could give valuable information with regard to football performance. The key requirement of a monitoring assessment, that can be applied to inform the recovery of well-being and physical performance, is that it should be sensitive to the training and competition dose (Thorpe et al., 2017). If such monitoring assessments are sensitive to the training dose, the temporal application of these assessments could be indicative of aspects of recovery and inform the manipulation of the training and competition dose. Hence, coaches and sport science could effectively prescribe training on a day to day basis reducing the risk of an imbalance between training stress and subsequent recovery which may result in reduced well-being, NFOR and a decline in football performance.

Several subjective and objective monitoring assessments that are indicative of the training response have been identified. Performance tests (e.g. maximal aerobic and neuromuscular assessments) which are representative of players' physical performance capacity are considered the ultimate marker of a player's physical response to the training dose and readiness to perform (Saw et al., 2016). Unfortunately, maximal tests are time consuming, likely to exacerbate stress and are not viable on a daily basis (Twist and Highton, 2013). To address these issues, objective physiological (e.g. submaximal heart rate (HR) at fixed exercise intensity), biochemical (e.g. creatine kinase) and subjective self-report questionnaire assessments have been proposed (Halson, 2014). Recently, subjective questionnaires developed 'in-house' by sport science practitioners which involve the self-report of the multi-dimensional components well-being have received considerable attention (Saw et al., 2016).

Their utility on a daily basis and greater sensitivity to acute (daily), short-term (1-8 weeks) and chronic training loads in comparison with objective assessments make subjective questionnaires a promising assessment tool (Saw et al., 2016).

However, well-being may not translate directly to the player's ability to perform physically. For example, a player experiencing increased perceptions of stress, fatigue and poorer perceptions of recovery may not have a reduced physical performance capacity (Faude et al., 2011). This highlights the multi-faceted nature of both well-being and physical performance such that a single daily monitoring assessment is unlikely to identify both the player's well-being and ability to perform physically. Hence, developing and applying an interdisciplinary mixed methods approach using a combination of well-being and physical performance assessments is required (Le Meur et al., 2013). Given the potential contribution of well-being and physical performance to football performance (Faude et al. 2014; Saw et al. 2016), these assessments are a promising tool for coaches and sport science practitioners. The ideal combination of methods used may vary over time depending on their utility in assessing acute, short-term and chronic well-being and physical performance. Such an approach may build an accurate depiction of player well-being and physical performance enabling coaches and sport science practitioners to make informed choices with regard to training periodisation.

The selection of these assessments in elite youth football must: be appropriate to the resources available at the club; provide concise, timely and meaningful feedback; give valuable information on the dose-response relationship and inform player management. Elucidating the sensitivity of these monitoring assessments (e.g. high vs. low load) to changes in stress, induced by different acute training is required to determine the validity of the selected subjective monitoring assessment. Furthermore, the temporal application of these assessments to elite youth football players to assess the recovery of well-being and physical performance during intense training and competition periods, at short-term and chronic time points throughout the season, would enable coaches and sport science practitioners to more effectively periodise training and develop player management strategies. The reliability, sensitivity and application of these methods in elite youth players has not previously been defined.

The ergonomics of the training process in elite football requires players to be monitored on a group and individual basis. Training is undertaken as a group therefore the design and manipulation of training periodisation is normally considered at a team level. Hence, identifying group trends may assist in the management of the training process. However, monitoring carried out solely at a group level does not account for individual differences. Differences in positional requirements, exposure to competitive matches, level of fitness, level of recovery, genetic predisposition to training and other life factors will result in each player receiving a different internal training dose (Impellizzeri et al., 2005). Therefore, an idiosyncratic response is likely even if the players are exposed to similar external load in group training. This highlights a need to develop an individual approach to analysis and feedback to provide coaches with the information to enable them to make informed choices with regard to training periodisation which may assist in managing the development of each individual player.

1.1 Aims and objectives

Establishing ecologically valid monitoring assessments sensitive to training stress and associated recovery may assist in player management strategies which inform training periodisation and ultimately enhance development of elite youth football players. Therefore, the overall aim of the thesis is to investigate the utility of bespoke well-being and physical performance assessments in the management and development of elite youth football players (U18) at a category two academy. Accordingly, the objectives of the thesis are to:

- Investigate associations between subjective well-being questionnaire items developed 'in-house' by the sport science practitioners at a category two academy and previously validated questionnaires (chapter 3).
- Identify the day to day reliability of well-being questionnaire items developed 'in-house' by the sport science practitioners at the club (chapter 3).
- Identify the day to day reliability of objective physical performance assessments (chapter 3).
- Identify the validity of various HR based assessments of the internal training dose (chapter 3).
- Assess the sensitivity of well-being and physical performance assessments to changes in training stress, induced by different training loads, and identify group and individual responses to the same given external training load (chapter 4).
- Evaluate well-being and physical performance responses, in elite youth football players, across a five week pre-season training period and explore the triangulation of monitoring assessments applied to monitor an individual's training response (chapter 5).

- Assess changes in perceptions of well-being and physical performance throughout a season in elite youth footballers (chapter 6).

CHAPTER 2

2.0 Literature review

The purpose of this literature review is to provide background information on youth development models in elite English youth football and identify aspects of physical performance needed to excel at an elite level of English senior and youth football. The influence of training and competition on well-being and physical performance is considered and monitoring assessments which may be applied to assist in the management and development of Elite Youth football players are reviewed.

2.1 Youth development pathways in English football – a brief history

The standard of players available for selection is paramount to success in football (Williams and Reilly, 2000). Professional teams have a vested interest in developing their own players due to the competitive market and financial cost of sourcing the best players. Hence, the development of home grown talent in England is critical to the success of English clubs. Player development is a dynamic and complex process in which the interaction of performance, educational and social factors must be accounted for to optimally nurture elite youth football players (Burgess and Naughton, 2010).

Prior to 1997 no coherent youth development model existed. The role of the schools, the English Football Association (FA) and the professional clubs in player development were ambiguous and lacked a strategic approach (Wilkinson, 1997). In 1997, the F.A Technical Director, Howard Wilkinson, introduced the 'charter for quality' (Wilkinson, 1997). The keystone to the 'charter for quality' was to identify players of outstanding potential and provide an environment which supported them to attain football excellence. The responsibility of player development was placed on the professional clubs through an academy system. To attain academy status professional clubs had to attain several criteria based on facilities, player to coach ratio, coaching contact time, coach education, medical support and sport science support.

In 2006, the football authorities (The FA, Premier League and Football League) invited Richard Lewis to produce a report on the structure of youth development in England (Lewis, 2007). The key factor influencing the commissioning of the report was the lack of world class home grown players playing in the senior national team and the Premier League. The Lewis report identified the positive steps that had been made with the introduction of the charter for quality a decade earlier. However, changes in the quality of facilities, coaching provision and support services were needed to develop world class home grown talent. The report urged all key stakeholders, including the FA, Premier League and Football League, to work together to create a new youth development model that would produce world class players for the senior national team, Premier League and Football League clubs. However, the finance, organisation and kudos of the Premier League clubs affords them jurisdiction on the governance of elite youth football development. Based on some of the recommendations set out in the Lewis report, the Premier League implemented a new youth development model in the 2012-2013 season termed the elite player performance plan (EPPP).

2.1.1 Elite Player Performance Plan

The primary focus of the EPPP is to create an elite training environment to nurture home grown talent. The EPPP recognises the responsibility of the Premier League and Football League clubs to develop home grown players and outlines a development model which accounts for the specific needs of each club. The development model aims to produce world class home grown players capable of playing in the each club's first team through providing players with the best coaching, facilities and support. This world class academy system is proposed to give English clubs access to the best players in the world, an advantage over their international competitors and value for money through reducing the need to recruit players via transfer fees. The EPPP measures the performance of each academy based on 292 key performance indicators (KPIs). These KPI's are informed by the six fundamental principles viewed to be critical to the successful development of elite football players (Table 2.1). Success in each of these KPIs is assessed by independent auditors and determines which category status a club is awarded [category 1 (highest) to 4 (lowest)]. Therefore, the category each club is awarded is dependent on performance and reflective of the financial investment, resources and facilities provided by each club. This structure provides four development models (category 1 to 4) specific to the needs and resources available to each club.

Table 2.1. Fundamental principles critical to the success of player development, as set out by the elite player performance plan (EPPP).

1	increase the number of home grown players playing at the highest level
2	increase the coaching contact time
3	improve the quality of coaching
4	implement effective metrics for quality assurance
5	provide value for money
6	seek to improve all aspects of player development

Within the new EPPP structure, the process of developing elite players is split into three distinct development phases; the foundation phase (FP; U5-U11 yrs), the youth development phase (YDP; U12-U16 yrs) and the professional development phase (PDP; U17-U21 yrs; The Premier League, 2011). The aim of each development phase is to identify bespoke age specific solutions to enhance long term player development. In the PDP there is a high stipulated training volume (12-14 h per week) to develop the players technically and tactically. Yet, in the PDP 'winning has to matter' (The Premier League, 2011). This creates a conflict between the deliberate practice time, considered an important aspect of skill acquisition, and attainment of the appropriate training stimulus, with adequate subsequent recovery, to facilitate optimal physical performance.

2.1.2 Deliberate practice time

The youth development model set out in the EPPP identified an increase in coaching contact time, to enhance skill acquisition, as a cornerstone for elite player development in England (The Premier League, 2001). The Premier League (2011) suggested the youth development model set out by the FA charter for standards in 1998 was giving English players reduced practice time across the entire development pathway in comparison with their European counterparts (~3760 h contact time in comparison with ~4880 h, ~5740 h and ~5940 h for elite players in Spain, France and Holland respectively). In addition, the Premier League (2011) suggested the total hours of contact time for elite football players was lower in comparison with other UK elite environments such as Yehudi Menuhin Music School (~10840 h), The Royal Ballet School (~10000 h), British Cycling (~10000 h), British Swimming (~8360 h) Lawn Tennis (~8160 h) and the English Cricket Board (~6760 h).

Based on the premise of the 10000 hour rule, the Premier League (2011) set out a minimum of coaching contact time for players (Table 2.2). The aim was to achieve a ~2 fold increase in practice time with players accruing ~8500 hours over the development pathway. However, the increase in practice time was aimed at the players in the FP and YDP. Contact time in the

PDP remained similar to previous recommendations set out in the 1998 FA Charter for Standards (12 h per week; Wilkinson, 1997).

Table 2.2. Number of hours coaching contact time required in each development stage for each academy category.

	Foundation Phase (FD)	Youth Development Phase (YDP)	Professional Development Phase (PDP)
Category 1*	4-8 h	10-12 h	12-14 h
Category 2*	3-5 h	6-12 h	12-14 h
Category 3	3 h	4-6 h	12 h
Category 4	N/A	N/A	12 h

FP (U5 to U11); YDP (U12-U16); PDP (U17-U21). Hours based on a 40 week season. * From U15 upwards hours based on a 46 week season (The Premier League, 2011).

The 10000 hour rule and its association with elite performance and skill acquisition has been criticised and misinterpreted. Recent reviews of practice time and elite performers suggest in the context of developing elite football players 10000 hours is not a necessity (Ericsson, 2013, Tucker and Collins, 2012) and other factors such as genetic predisposition are important to player development in elite football (Tucker and Collins, 2012). However, it has been reported elite players who accrued more practice time in childhood played at a higher standard of football (Helsen et al., 2000). This suggests engagement in deliberate practice is required to develop elite players.

Anecdotally, it seems that coaches and football academies have contrasting approaches to player development in the PDP with regard to the trade-off between practice time and maximising physical characteristics. This is evidenced by the disparity in training time reported in elite youth players (U18). The high training exposure previously reported in elite Scottish youth players (~10 h per week) suggests the coaches are focusing on deliberate practice through a high number of coaching contact hours (McMillan et al., 2005a). In contrast, two English category one academies reported much lower training hours (~5 h) in U18 players during weekly in-season microcycles with a single competitive fixture (Enright et al., 2015, Malone et al., 2015b). Similar weekly training volumes (~4h) are common in elite senior teams during in-season competition periods to maximise physical performance (Anderson et al., 2016, Verheijen, 2014).

This section (2.1) highlights that a potential conflict between optimising physical characteristics and accruing adequate practice time exists. The subsequent section (2.2) outlines the contribution of physical characteristics to football performance.

2.2 Football performance

Football performance is multifactorial with technical, tactical, physiological and psychological characteristics contributing holistically. Several technical, tactical, physiological and psychological KPI's have been identified (Hughes et al., 2012), yet attempting to ascertain the contribution of each KPI is challenging (Rosch et al., 2000). Players have differing positional requirements and abilities which subsequently affects the contribution of each KPI, creating unique performance outcomes which ultimately determine success and failure. It is important elite youth players develop the technical, tactical, physical and psychological characteristics to excel at an elite level (Bate et al., 2010).

During 90 minutes of match play each player is involved in ~1000 – ~1400 brief actions (Stolen et al., 2005) which include attacking, defending and the transition between (Table 2.3). Many technical, tactical, physiological and psychological factors influence the performance of each of these football actions. For example, factors such as technique and decision making will have a large impact on shooting success (Bate et al., 2010; Hughes et al., 2012). In addition, the importance of the speed of the initial action and the ability to subsequently maintain and repeat football specific actions over a 90 minute period highlights the contribution of physical factors to overall match performance (Bangsbo, 1994, Bangsbo et al., 2006b, Bishop et al., 2011).

Table 2.3. Football actions in match play (Bate and Peacock 2010; Hughes et al 2012).

Attacking	Defending
Shooting	Heading
Heading	Tackling
Passing (short/long)	Blocking
Dribbling	Dropping out
Running with the ball	Marking
Crossing	Contesting 1 v 1
Receiving	Covering
Dispersal	Intercepting
Supporting Play	Clearing
Counter attacking	Compact positioning
Retaining possession	Squeezing up
Creating space	
Penetrating	

2.2.1 Physical match demands

The physical demands of match play in elite football have been researched extensively during the previous 40 years with numerous motion analysis studies identifying the activity patterns of elite players (Bangsbo et al., 1991, Barnes et al., 2014, Bradley et al., 2013b, Bush et al., 2015, Stolen et al., 2005, Reilly and Thomas, 1976). Early studies reported a range of mean total distance covered per match of between 3300 m and 11500 m (Thomas and Reilly 1976, Whitehead 1975, Winterbottom, 1952) in professional English players. The differences in these studies likely reflect the variance in accuracy of the manual tracking methods employed.

In recent years, the use of video cameras and more advanced tracking technologies has improved the accuracy of notation. In the late 1990's Rienzi et al., (2000) reported a mean total distance covered of 10104 ± 703 m in six English Premier League players. A few years later Bradley et al., (2009) reported a mean total distance covered of 10714 ± 991 m in 370 individual performance observations during the 2005-2006 season. Recently, Barnes et al., (2014) reported total distance covered remained similar when assessed across a seven season period from 2006-2007 to 2012-2013 using 14700 individual performance observations (10679 ± 956 m vs 10881 ± 885 m). Although the majority of activity profile research in elite English football has focused on senior players, Saward et al., (2015) reported a similar mean total distance (~10500 m) in elite English Youth players (U18) across three seasons (2010-2011 to 2012-2013). These findings highlight the aerobic nature of football with similar demands at senior and youth levels of English football. In addition, the total distance covered at the highest level of senior English football has remained relatively consistent in the last 15-20 years.

The aerobic nature of the game is further highlighted by the contribution of aerobic metabolism during match play (Stolen et al., 2005). Adenosine Triphosphate (ATP) resynthesis via aerobic metabolic pathways is responsible for greater than 90 % of the total energy consumption during match-play (Bangsbo, 1994) and enables players to resynthesise ATP between high intensity actions (Reilly et al., 2000, Reilly, 2005, Stolen et al., 2005). The high aerobic energy contribution in football specific exercise is often assessed using HR measures due to the established relationship between HR and $\dot{V}O_2$ (Bangsbo et al., 2007). Mean HR values have been reported to be between 83 % and 87 % HR max during match play in elite senior players (Ascensao et al., 2008, Krustrup et al., 2011) with similar, 82 % to 87 % HR max, values observed in youth team players (U17 to U19; Helgerud et al., 2001, Rebelo et al., 2014). The similarities in aerobic energy contribution and mean total distance covered demonstrate the aerobic demands of Elite senior football do not differ in comparison with Elite youth football (U18).

In recent years, greater attention has been paid to the high intensity bursts within match-play. The emphasis placed on high intensity actions is prevalent due to the repeated sprint nature of the game and the defining football actions that occur in these high intensity bursts (Bangsbo, 1994, Silva et al., 2015). Saward et al., (2015) reported that the mean distance covered at high intensity (>21 $km \cdot hr^{-1}$) during a match was lower in elite youth players (U18) than previously reported in Elite Premier League players (~525 m vs 1151 m; Barnes et al., 2014). However, differences in velocity thresholds used to define high intensity distance (>19.8 $km \cdot hr^{-1}$ vs >21.0 $km \cdot hr^{-1}$) make comparisons between studies in elite English senior football and elite youth football difficult. Work on elite senior French players (Ligue 1) reported similar high intensity distances (~550 m; Dellal et al., 2010) in comparison to elite English youth players (~525 m) using the same high intensity velocity threshold (>21 $km \cdot hr^{-1}$). Therefore, it can be speculated that the high intensity activity profiles of elite youth players (U18) do not differ in comparison with elite senior players.

The increased prevalence of high intensity actions in recent years is apparent in elite English senior football. Barnes et al., (2014) reported ~30 % increase in mean high intensity distance covered (>19.8 $km \cdot hr^{-1}$: 1151 ± 337 m vs. 890 ± 299 m, $P<0.001$, moderate effect) , ~35 % increase in mean sprint distance covered (>25.1 $km \cdot hr^{-1}$: 350 ± 139 m vs. 232 ± 114 m, $P<0.001$, moderate effect) and ~85 % increase in mean sprint number (57 ± 20 vs. 31 ± 14, $P<0.001$, large effect) in 2012/2013 compared to 2006/2007 in the English Premier League. These evolutionary trends highlight the increased proportion of total distance covered at high intensity in elite senior English football. This is likely to reflect an increased recognition of the importance of high intensity actions during match play (Bangsbo et al., 2006b, Silva et al., 2015).

The defining moments in the game often require players to produce high force in a short period of time (Silva et al., 2015, Stolen et al., 2005). Therefore, high levels of performance require well developed anaerobic energy systems and neuromuscular function. Match play involves 150-250 brief intense actions (Bangsbo et al., 2006a, Mohr et al., 2003) with blood lactate concentrations ranging between ~2 and 14 $mmol \cdot l^{-1}$ across a whole match (Bangsbo et al., 1991, Bangsbo, 1994, Ekblom, 1986, Krustrup et al., 2006). These factors demonstrate the intermittent anaerobic demand and stochastic nature of competitive match play. Hence, sport science practitioners need to focus on the physical preparation of elite players to enable them to excel during high intensity actions (Bangsbo et al., 2006b, Silva et al., 2015).

During short intense periods of match play, players' physical capacity (aerobic, anaerobic and neuromuscular) may be maximally taxed resulting in temporal fatigue. Bradley et al., (2009) reported temporal fatigue during English Premier League match-play with a 6 % decline in high intensity distance covered in the five minute period immediately following (126 ± 52 m) the most intense five minute period (231 ± 53 m) in comparison with all other five minute periods (134 ± 35 m; P=0.03). Therefore, successful performance during the most intense periods of the game may be heavily influenced by the player's physical fitness.

The amount of high intensity distance covered has been proposed to differentiate between top class and moderate level professional football players. Mohr et al., (2003) reported 18 top class players (elite Italian) with a greater physical capacity (Yo-Yo intermittent recovery test level 1 (Yo-Yo IRT1): 2260 m ± 80 m vs. 2040 ± 60 m, P<0.05) covered a 58 % greater mean high intensity distance (>15 $km{\cdot}hr^{-1}$: 2430 ± 140 m vs. 1900 ± 120 m, P<0.05) and a 28 % greater mean sprint distance (>30 $km{\cdot}hr^{-1}$: 650 ± 60 m vs. 410 ± 30 m, P<0.05) than their less elite counterparts (24 Danish players) over a period of seven matches. Similarly, professional Danish players in top ranked teams had a 28 % greater physical capacity (Yo-Yo IRT1) and covered 38 % greater high intensity distance and 42 % greater total sprint distance (P<0.05) during the most intense five minute periods during match-play compared with players in bottom ranked Danish teams. These authors claimed that these findings give high intensity distance good construct validity as a physical performance measure. In contrast, Bradley et al., (2013a) reported high intensity distance covered does not discriminate between playing standard in English professional football. English Premier League players (947 individual performance observations) covered less total mean distance (10722 ± 978 m vs. 11607 vs. 737 m, P<0.05), mean high intensity distance (19.8 $km{\cdot}hr^{-1}$ to 25.1 $km{\cdot}hr^{-1}$: 681 ± 215 m vs. 881 ± 200 m) and mean sprint distance (> 25.1 $km{\cdot}hr^{-1}$: 248 ± 119 m vs. 360 ± 123 m) in comparison with less elite English League One players (867 individual performance observations). All players had a similar physical capacity determined by Yo-Yo intermittent recovery test level two (Yo-Yo IRT2; 2364 ± 478 m vs. 2226 ± 432 m for Premier League and League One players, respectively). The differences in these studies are likely to be a result of several confounding factors which influence player workload during match play. Hence, high intensity distance in match-play cannot be used to identify the physical fitness of players as the demands of the game may not maximally tax players' physical characteristics.

The variation in player workload highlights the limitations of using activity profiles as a physical performance measure. Previous studies have reported a large match to match variation in elite Premier League players. Gregson et al., (2010) reported large intra-individual between match variation for high intensity distance [Coefficient of variation (CV): 22.0 ± 22.1 %], sprint distance (CV: 38.9 ± 29.9 %) and sprint number (CV: 34.4 ± 27.4 %) in a four week period during the 2005/2006 season where players (n=37) competed in a minimum of eight competitive fixtures. The contribution of other factors such as the level of opposition (Rampinini et al., 2007b), state of the game (Lago-Peñas, 2012), home advantage (Lago-Peñas, 2012), tactics and formation (Bradley et al., 2011), technical performance (Bradley et al., 2013a) and stage of the season (Mohr et al., 2003) highlight activity profiles are not solely determined by physical fitness.

In addition to intra-individual variation, studies in elite Premier League players have reported differences between player positions. Bradley et al., (2009) profiled 370 elite English Premier League players and reported central midfielders (11450 ± 608 m) and wide midfielders (11535 ± 993 m) covered a greater total distance (P<0.05) in comparison with full backs (10710 ± 589 m) attackers (10304 ± 1175 m) and central defenders (9885 ± 555 m). In addition, wide midfielders covered a greater high intensity distance (19.8 $km \cdot hr^{-1}$ to 25.1 $km \cdot hr^{-1}$) in comparison with all other positions (1214 ± 251 m vs. 603 ± 132 m, 984 ± 195 m, 927 ± 245 m and 955 ± 239 m for wide midfielders vs. central defenders, full backs and central midfielders and attackers, respectively, P<0.05). Furthermore, full backs (287 ± 98 m) and wide midfield players (346 ± 155 m) covered a greater sprint distance (>25.1 $km \cdot hr^{-1}$) in comparison with central midfielders (204 ± 89 m) attackers (264 ± 87 m) and central defenders (152 ± 50 m). These findings demonstrate positional differences in activity profiles and the large standard deviations within positon indicate differences in the activity profile of players playing in the same position.

In summary, the myriad of factors influencing activity profiles highlight the complex and multifaceted components of physical performance in elite senior and youth football. Activity profiles are useful to determine the physical demands of match-play but cannot be used to identify the physical fitness of players. Physical fitness is an important contributor to successful performance outcomes during match play allowing players to excel during the most intense periods of match-play. Hence, developing players' physical characteristics through appropriate training periodisation (Section 2.4.6) is an important aspect of maximising player performance.

2.3 Physical performance characteristics of elite players

The physiological demands of match-play identified in the previous section (2.2) highlight the need for well-developed physical characteristics. Physical performance is aligned to a high level of aerobic, anaerobic and neuromuscular fitness (Bangsbo et al., 2006b, Silva et al., 2015, Stolen et al., 2005). The physical characteristics of elite senior and elite youth players are outlined in this section (2.3).

2.3.1 Aerobic characteristics of elite players

Reilly et al., (2000) suggested a maximal oxygen uptake ($\dot{V}O_2$ max) value above ~60 $ml \cdot kg^{-1} \cdot min^{-1}$ is required in match play to allow adequate ATP resynthesis between high intensity actions. A range of studies have reported mean $\dot{V}O_2$ max values in elite senior players and elite youth players to be between 55 $ml \cdot kg^{-1} \cdot min^{-1}$ and 70 $ml \cdot kg^{-1} \cdot min^{-1}$ (Boone et al., 2012, Helgerud et al., 2001, McMillan et al., 2005a, Stolen et al., 2005). Similar mean $\dot{V}O_2$ max values have been reported in elite English youth players (62 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$; Enright et al., 2015). The relatively large standard deviation observed in elite youth players (5 $ml \cdot kg^{-1} \cdot min^{-1}$) is likely to reflect factors such as genetic predisposition (Stolen et al., 2005), playing position (Boone et al., 2012, Reilly et al., 2000) and environmental factors (e.g. training; McMillan et al., 2005a).

The measurement of the onset of blood lactate accumulation, often assessed as speed at a fixed blood-lactate concentration of 4 $mmol \cdot l^{-1}$ (S4) is considered a more sensitive predictor of aerobic performance in comparison with $\dot{V}O_2$ max (McMillan et al., 2005a) and has commonly been used to assess aerobic fitness in elite football players (Akubat et al., 2012, Castagna et al., 2011, Manzi et al., 2013). To the authors knowledge no data exists on S4 values in elite English senior players or English youth players. Elite Italian senior players have reported S4 values between 13.0 ± 0.8 $km \cdot hr^{-1}$ and 14.9 ± 1.5 $km \cdot hr^{-1}$ (Castagna et al., 2011, Castagna et al., 2013, Manzi et al., 2013) with similar S4 values reported in U18 Scottish elite youth players (13.6 ± 0.2 $km \cdot hr^{-1}$ to 14.7 ± 0.2 $km \cdot hr^{-1}$; McMillan et al., 2005a).

2.3.2. Anaerobic and neuromuscular characteristics of elite football players

Aerobic based tests are not appropriate to assess high intensity intermittent exercise as they do not induce a high anaerobic energy demand (Bangsbo et al., 2008). High intensity intermittent field tests, such as the Yo-Yo IRT1 and Yo-Yo IRT2 have been developed and are applied to assess the capability to undertake repeated high intensity activity (Bangsbo et al., 2008). Yo-Yo IRT1 performance in elite European senior players has been reported to be between 2000 ± 279 m and 2390 ± 409 m (Castagna et al., 2013, Ingebrigtsen et al., 2012, Mohr et al., 2003) with evident differences between playing position (Mohr et al., 2003), player standard (Mohr et al., 2003, Ingebrigtsen et al., 2012) and time point within the season (Castagna et al., 2013). Bangsbo et al., (2008) reported a similar Yo-Yo IRT1 distance in elite youth players (~2100 ± 80 m) in comparison with elite senior players (2000 ± 279 m to 2390 ± 409 m) suggesting the high intensity intermittent exercise capacity of elite youth players does not differ from that of senior elite players.

Sprint and CMJ assessments are commonly used to assess neuromuscular performance in elite football players. A large variation in sprint and jump performance in elite senior players and elite youth players has been reported (Table 2.4) with differences observed between playing position (Sporis et al., 2009) and player standard (Cometti et al., 2001). However, the large variation observed between studies, on elite players and elite youth players, is likely due to methodological issues associated with collecting performance data, such as test set up, instructions, the equipment used and whether peak or average test performance was used in analysis (Rumpf et al., 2011).

Agility tests are applied to evaluate the capability to change direction rapidly, which is critical to success in the defining moments of the game (Bloomfield et al., 2007). Successfully changing direction quickly during match situations is dependent on both the player’s ability to change direction and a perceptual decision making component (Young and Willey, 2010). Agility tests which incorporate both a change of direction and a perceptual decision making component are difficult to design and implement. Therefore, change of direction is often assessed in elite footballers in the absence of a perceptual decision making component. Various tests to assess change of direction have previously been used such as the t-test, slalom test (Sporis et al., 2010), 505 agility test (Thomas et al., 2009) and the arrowhead agility test (AAT; Chan and Chan, 2010, Harsley et al., 2014). The AAT has previously been used to assess change of direction in professional players from Hong Kong (8.16 ± 0.20 s; Chan and Chan, 2010) and elite English U18 youth footballers (7.93 ± 0.14 s; Harsley et al., 2014; Table 2.4).

Table 2.4. Sprint performance, countermovement jump (CMJ) performance and arrowhead agility (AAT) performance in senior and elite youth football players.

	Elite Player population	Performance	Study
5 m Sprint	Senior Spanish	1.00 ± 0.03	(Silva et al., 2014)
	Senior Brazilian	1.10 (4.55 ± 0.21 $m \cdot s^{-1}$)	(Loturco et al., 2015)
	Youth German (U17/U19)	1.00 ± 0.06	(Faude et al., 2014)
10 m Sprint	Senior French	1.80 ± 0.06	(Cometti et al., 2001)
	Senior Spanish	1.87 ± 0.07	(Helgerud et al., 2011)
	Youth English (U18)	1.58 ± 0.06	(Lovell et al., 2015)
	Youth Scottish (U18)	1.96 ± 0.07	(McMillan et al., 2005b)
20 m Sprint	Senior Brazilian	2.98 (6.72 ±0.19 $m \cdot s^{-1}$)	(Loturco et al., 2015)
	Senior Spanish	3.13 ± 0.11	(Helgerud et al., 2011)
	Youth English (U18)	2.85 ± 0.10	(Lovell et al., 2015)
	Youth Brazilian (U20)	2.95 s (6.77± 0.19 $m \cdot s^{-1}$)	(Loturco et al., 2016)
30 m Sprint	Senior Norway	4.00 ± 0.20	(Wisloff et al., 2004)
	Senior Danish	4.44 ± 0.03	(Krustrup et al., 2011)
	Youth Brazilian (U20)	3.97s (7.55 ± 0.21 $m \cdot s^{-1}$)	(Loturco et al., 2016)
	Youth German (U17/U19)	4.12 ± 0.13	(Faude et al., 2014)
	Youth English (U18)	4.22 ± 0.23	(Enright et al., 2015)
CMJ	Senior French	40 ± 2	(Nedelec et al., 2014)
	Senior Spanish	60 ± 5	(Helgerud et al., 2011)
	Youth English (U18)	36 ± 5	(Malone et al., 2015b)
	Youth German (U17/U19)	39 ± 4	(Faude et al., 2014)
	Youth English (U18)	61 ± 4	(Harsley et al., 2014)
AAT	Senior Hong Kong	8.16 ± 0.20 s	(Chan and Chan, 2010)
	Youth English (U18)	7.93 ± 0.14 s	(Harsley et al., 2014)

Sprint times and AAT reported in (s). CMJ reported in (cm).

2.4 Ergonomics model of training and competition in elite youth football

Football training is a holistic process in which varied modalities are selected to optimise technical, tactical, psychological and physical performance (Reilly, 2005). It is important that elite youth players develop the technical, tactical, physical and psychological characteristics which define elite performance (section 2.2). In section 2.1.1 the trade-off between maximising physical performance and the high number of prescribed training hours highlighted the challenges coaches face in periodising training in elite youth players in the PDP. It is important that the physical characteristics outlined in section 2.3 are optimised. However, exposure to high training volumes in the absence of adequate recovery may result in NFOR and / or a reduction in well-being. The subsequent sections identify the fundamental principles of training adaptation (section 2.4.1) and the impact high training loads have on well-being and physical fatigue (sections 2.4.2, 2.4.3, 2.4.4, 2.4.5) in elite youth football players.

2.4.1 Training responses

The fundamental principles of the adaptive response to training need to be considered when periodising training in elite youth football players (Budgett, 1998; Figure 2.1). Following a training stimulus, stress results in an initial decrease in physical performance. If recovery is sufficient this is followed by a super-compensatory adaptive response and an increase in physical performance (Budgett, 1998). Therefore, the training outcome is dependent on the dose (frequency, intensity, duration and modality), the magnitude of resultant stress and the associated time course of recovery (Budgett, 1998, Bishop et al., 2008, Reilly and Ekblom, 2005). If the training stress or non-training stress is matched by subsequent adequate recovery it is more likely that the player will either maintain or improve physical performance.

Conversely, if the training stress or non-training stress is not matched by subsequent adequate recovery, a maladaptive response may impair physical performance which is often but not always associated with a reduction in well-being (Budgett, 1998, Kentta and Hassmen, 1998).

Figure 2.1. The balance of training and recovery (Budgett 1998)

Stress and the time course of physical recovery have been differentiated between, within a consensus statement, by the European College of Sports Medicine and American College of Sports Medicine (Meeusen et al., 2013; Figure 2.2). Acute physical fatigue is characterised by a transient impairment in physical performance with a short time course of physical recovery lasting hours or days. As competition and training intensifies, the magnitude of stress and the time course of physical recovery increases, physical performance decrements are exacerbated and there is an increase in the severity of symptoms associated with stress and inadequate physical recovery. Functional overreaching (FOR) is defined by a transient decrement in physical performance and has a time course of physical recovery lasting days or weeks. Acute physical fatigue and FOR are considered a necessity to improve physical performance (Figure 2.1). In contrast, NFOR and OTS are characterised by a reduction in physical performance which last for weeks or months. This physical performance decline is often associated with a reduction in well-being linked to symptoms such as increased mood disturbances, fatigue and muscle soreness, reduced appetite, overuse injuries and altered sleep patterns (Meeusen et al., 2006). Hence, it is important that each player's training load and competition load are managed to reduce the risk of reduced well-being and impaired physical performance.

Figure 2.2. Definitions of acute physical fatigue, functional overreaching (FOR), non-functional overreaching (NFOR) and overtraining syndrome (OTS) based on the impact of intensified training and associated recovery on physical performance (Meeusen et al., 2013).

Much of the research to develop a consensus on FOR, NFOR and OTS has focused on endurance athletes (Meeusen et al., 2013, Nederhof et al., 2006, Nederhof et al., 2008). The competition schedules in endurance events and elite youth football are different. Endurance events require athletes to peak on far fewer occasions (~3 times) throughout a shorter competitive season in comparison with elite youth football players in the PDP who participate in a ~38 week in season competition phase involving weekly competition (Issurin, 2010). Hence, the time course of physical recovery which is conceptualised as FOR in endurance athletes (days/weeks) may not be functional in elite youth football players. The transient decreases in physical performance associated with FOR over a period of several days or weeks are undesirable in the competitive football in-season phase given the regular competitive fixture demands (Carling et al., 2015a, Gamble, 2006). Hence, NFOR in elite youth football could be considered as a transient decrement in performance that presents prior to a competitive fixture.

2.4.2 Player well-being

The negative impact of high training loads on perceptions of well-being in elite athletes has been consistently reported in the literature (Faude et al., 2011, Kellmann and Kallus 2001, Morgan et al., 1987). Furthermore, impaired physical performance has been associated with reductions in well-being (Meeuson et al., 2013). Interestingly, Saw et al., (2016) proposed that the best measure of well-being is performance. However, poorer perceptions of well-being have been associated with both a decrease (Brink et al., 2012) and no impairment (Faude et al., 2011) in physical performance in elite youth football players following exposure to high training and competition volumes. These inconsistent findings highlight that reduced well-being does not necessarily influence physical performance but may increase the likelihood of poorer physical performance.

In addition to high training loads, several other off-field risk factors may influence well-being (Table 2.5). These risk factors highlight that well-being is multi-factorial and complex. Well-being is perceptual and therefore a psychological measure that is influenced by the interaction of a range of physical, behavioural, environmental and genetic constructs (Scully et al., 1998). Regardless of whether a decrement in physical performance is observed a reduction in well-being could influence other aspects of football performance. Furthermore, a reduction in well-being is likely to have a detrimental impact on their development as an elite youth football player. For example, a reduction in well-being could influence how players engage in the processes (e.g. training, social, educational) which are designed to optimise player development (Burgess and Naughton, 2010, Mitchell et al., 2014). Coaches and sport science practitioners have a duty of care to protect and nurture players and therefore must endeavour to ensure player well-being.

Table 2.5. Risk factors influencing player well-being (Queensland Academy of Sport 2014, Ivarsson et al., 2015).

2.4.3 Physical fatigue

Physical fatigue is a complex and multifaceted phenomenon (Halson 2014; Noakes et al., 2005, St Clair Gibson and Noakes, 2004). A variety of definitions of physical fatigue have previously been proposed which often reflect the experimental model used and the conditions under which 'fatigue' occurs (Halson 2014). For the purpose of this thesis, physical fatigue will be defined as the inability to perform a physical task which was once attainable in a recent timeframe (Halson 2014; Thorpe et al., 2017)

Task failure has been indicated by a temporal decrease in physical performance during football match play (section 2.2.1), towards the end of match play (Bradley et al., 2009) and immediately following match-play (Nedelec et al., 2012). Evidence of temporal fatigue during match-play was highlighted in section 2.2.1. In addition, physical fatigue towards the end of match play was observed in elite English players with 21 % less high intensity distance covered in the final 15 mins of the game in comparison with the first 15 minute period within the game (374 ± 119 m vs. 466 ± 137, $P<0.01$; Bradley et al., 2009). Furthermore, a decrement in sprint (Ascensao et al., 2008, Rampinini et al., 2011) and jump performance (Magalhaes et al., 2010, Robineau et al., 2012) is consistently reported immediately following compared with immediately before match play in elite players. The mechanisms influencing physical fatigue during and following match play are task dependent with exercise specificity, duration and intensity inducing a variety of physiological, biochemical, biomechanical and psychological fatigue mechanisms. (Barry and Enoka, 2007, Enoka and Stuart, 1992, Inzlicht and Marcora, 2016, Noakes, 2012).

Enoka and Stuart (1992) identified nine potential mechanisms contributing to task failure (Figure 2.3) which are classified as either central (1-3, Figure 2.3) or peripheral (4-9, Figure 2.3) in origin (St Clair Gibson and Noakes, 2004).

Neuromuscular peripheral fatigue mechanisms are often associated with task failure following brief intense exercise (Barry and Enoka, 2007). However, Noakes (2012) proposed the central governor theory in which psychobiological mechanisms regulate exercise performance to prevent a catastrophic failure in homeostasis. Based on several feedforward and feedback components, which include biological and motivational state, it was suggested that the brain uses unpleasant illusory sensations of fatigue to govern exercise performance (Noakes, 2012). Hence, ultimately task failure during and following high intensity intermittent exercise is determined by feedback and feedforward processes which influence a conscious or unconscious mental decision to terminate exercise. This demonstrates the complex interactions between the multifactorial psychobiological fatigue mechanisms which result in task failure during and following training and match-play in elite football players.

Figure 2.3. Nine potential mechanisms contributing to fatigue 1) activation of the primary motor cortex 2) the central nervous system (CNS) drive to motor neurons 3) neural recruitment of motor units, 4) neuromuscular propagation, 5) excitation-contraction coupling, 6) substrate availability 7) intracellular milieu 8) contractile apparatus, 9) muscle blood flow (Enoka and Stuart 1992).

2.4.4 Time course of recovery

As detailed in section 2.4.1 training stress in the absence of adequate recovery following training and match play may result in NFOR and OTS. Assessments which identify the time course of recovery of both well-being and physical performance (section 2.5) could assist coaches and sport science practitioners to make informed decisions in regard to training prescription (section 2.4.6).

The time course of physical recovery will be dependent on the magnitude of stress and a multitude of factors influencing the subsequent recovery of physical performance. The complex factors influencing physical recovery are highlighted by the equivocal findings which identify a decrease or no change in neuromuscular performance (CMJ and sprint) 24 h, 48 h and 72 h post-match. The majority of the research suggests an aspect of neuromuscular performance (CMJ and sprint) remains impaired 48 h (Ascensao et al., 2008, Ascensao et al., 2011, Fatouros et al., 2010, Magalhaes et al., 2010) to 72h (Ascensao et al., 2008, Fatouros et al., 2010, Ispirlidis et al., 2008, Magalhaes et al., 2010) following match-play. Yet, physical performance has been shown to return to baseline level within a 48h (CMJ and sprint; Rampinini et al., 2011, Silva et al., 2013) and a 72h recovery period (CMJ, sprint and Yo-Yo IRT1; Krustrup et al., 2011; Silva et al., 2013).

One factor potentially influencing these findings is a disparity in the magnitude of stress, influenced by a varied external load and differing levels of fitness (Ispirlidis et al., 2008, Rampinini et al., 2011). Individual characteristics such as genetics and previous training history will influence the player's level of fitness and subsequent recovery time (Bishop et al., 2008). Furthermore, factors such as sleep, nutrition, hydration, alcohol, lifestyle, sleep and recovery interventions (e.g. cryotherapy; Barnett, 2006, Reilly and Ekblom, 2005) will affect the time course of physical recovery and be individual to each player (Bishop et al., 2008). This highlights the need for an individual approach to monitoring the time course of recovery (Section 2.6).

2.4.5 Evidence non-functional overreaching and reduced well-being

Elite English senior and youth players are both exposed to high training and / or competition loads. Elite youth players are exposed to higher training volumes (~12-14 h vs. ~4 h per week) in comparison with elite senior players (Anderson et al., 2016, The Premier League, 2011) yet, the fixture demands placed on elite youth elite players (U18s) are lower in comparison with elite senior player (~28 vs ~50 fixtures per season, 1 vs. 2 fixtures per week; Carling et al., 2015b; The premier league 2011). At lower category clubs (Category two, three and four) there is a tendency to have smaller first team and youth team squad sizes resulting in some elite youth players competing in both U18s and U21s fixtures (two matches per week). Hence, a combination of fixture congestion and high training volumes may put elite youth players at risk of NFOR.

High training and competition loads have been linked to players underperforming both technically and tactically (Ekstrand et al., 2004, Verheijen, 2012), an increase in injury rate (Bengtsson et al., 2013, Owen et al., 2015) and NFOR (Brink et al., 2012, Rollo et al., 2014). Fixture congestion has been shown to impair football performance in elite senior players. Ekstrand et al., (2004) suggested following a 10 week period of fixture congestion (13 vs. 9 matches), 32 % of elite European senior players' underperformed during the 2002 World Cup when subjectively evaluated by three international football experts. However, no changes in physical activity profiles during congested fixture periods (2 matches per week) have been observed in elite senior players (Carling et al., 2015a, Dellal et al., 2015, Dupont et al., 2010). This may highlight effective squad rotation and post-match recovery strategies at the elite senior level (Carling et al., 2015a, Carling et al., 2015b).

As discussed in section 2.2.1 a limitation to using activity profiles to assess physical performance is that they may fail to tax players' physical capacity. To the authors knowledge no study has assessed the impact of congested fixtures on physical capacity in elite senior players, however, Rollo et al., (2014) reported that sub-elite players had an impaired physical capacity (Sprint, CMJ, Yo-Yo IRT1) 48 h post-match (Rollo et al., 2014) following a six week congested fixture period (2 matches per week). It is acknowledged that differences in the level of fitness between elite and sub-elite players could influence the time-course of physical recovery, however the physical capacity of elite senior players may be impaired following fixture congestion.

Elite youth players may not be exposed to the fixture congestion demonstrated in elite senior football. However, a combination of high training volumes and weekly competitive fixtures increases the risk of NFOR and / or a reduction in well-being. Faude et al., (2011) reported training exposures of ~7h per week plus one competitive fixture resulted in poorer perceptions of well-being (increased perceptions of stress and decreased perceptions of recovery) towards the end of the season in elite German youth players (~U21, n=15). Furthermore, Brink et al., (2012) reported the prevalence of NFOR in elite youth Dutch players (U18; n=94) was 7.4 % over a period of two seasons. The diagnosis of NFOR was determined by a sports physician in a laboratory setting using the recommended guidelines (Meeusen et al., 2006). Players diagnosed with NFOR had an impaired physical performance (submaximal HR exercise test) and poorer perceptions of well-being (greater perceptions of stress and poorer perceptions of recovery) in comparison with baseline measures at the start of the season.

Evidence of NFOR in elite youth players highlights the challenges facing coaches and sport science practitioners working with elite English football players in the PDP. High training volumes of 12-14 h per week plus the focus on 'training to win' and maximising physiological characteristics makes effective training periodisation challenging. Hence, assessments are needed to monitor whether players are at risk of NFOR and / or a reduction in well-being. It is worthwhile noting that the incidence of NFOR (7.4 %) reported by Brink et al., (2012) implies that only 2-3 players in a squad of 20 players are likely to develop NFOR. Therefore, some individuals could be more susceptible to NFOR. This reinforces the need for an individual approach to monitoring elite youth football players.

2.4.6 Training periodisation in elite youth football

Training periodisation in elite youth football is challenging. Integrating technical, tactical, physical and psychological elements into training, the multifactorial physical requirements of football performance (Stolen et al., 2005), positional differences (Bloomfield et al., 2007), varied exposure to fixtures (Carling et al., 2015a, Gamble, 2006), individual training history, individual fitness levels, (Faude et al., 2014) individual time course of recovery (Bishop et al., 2008) and the trade-off between practice time and optimising physical characteristics make effective training periodisation for the team and the individual an intricate and complex process.

Effective training periodisation is dependent on prescribing the appropriate training dose to each player. Banister (1979) proposed that physical performance at any given time point is dependent upon the accumulation and decay of fitness and fatigue (Performance = fitness - fatigue). Hence, an athlete with high fitness and low fatigue has the potential to produce a good physical performance. In contrast, an athlete with high levels of fitness and high levels of fatigue or an athlete with low levels of fitness and low levels of fatigue would be more likely to perform poorly. Therefore, modelling the dose - response relationship with fitness and fatigue would allow coaches and sport science practitioners to gain valuable information allowing them to make informed decisions on each player's training dose and reduce the risk of NFOR and OTS.

Modelling endurance performance has been extensively researched in endurance athletes (Banister 1975, Banister et al., 1999, Busso et al., 1997, Morton et al., 1990). In endurance events, modelling the performance outcome is more simplistic in comparison with football. Endurance performance is determined by a single outcome (time) and is predominantly dependent on aerobic fitness. However, the multifactorial nature of physical performance in football makes it difficult to define. Furthermore, modelling requires frequent measures of physical performance which is not feasible due to the high frequency of competitive fixtures.

Although modelling physical performance in football may be difficult, the physical training outcome is ultimately dependent upon the internal load (Figure 2.4; Impellizzeri et al., 2005). This internal load is determined by the range of training practices that are prescribed by the coach (external training load), the current fitness / fatigue level of the individual player and their genetic potential (Impellizzeri et al., 2005). Football training consists of specific technical and tactical practices, small sided games (SSG), high intensity interval training (HIIT), strength training, speed training and agility training (McMillan et al., 2005a, Iaia et al., 2009, Hill-Haas et al., 2011). In elite youth football, coaches must select practices which develop the technical, tactical, physical (aerobic, anaerobic, and neuromuscular) and psychological aspects of player performance as noted in section 2.2., selecting the most appropriate training modalities, intensity, time and duration as required to optimise physical performance (Buchheit and Laursen, 2013a).

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Figure 2.4. The training process (Impellizzeri et al., 2005)

Often during the pre-season preparation phase, football coaches prioritise the development of physical qualities. This is considered necessary to regain fitness decrements associated with the off-season (Hill-Haas et al., 2009, Jeong et al., 2011). Conversely, during the in-season period the focus shifts to maintaining physical characteristics due to frequent competitive fixtures and a greater focus on tactical and technical aspects of performance (Gamble, 2006).

Improvements in aerobic fitness ($\dot{V}O_2$ max and S4) are associated with the pre-season period in elite senior and elite youth football players (McMillan et al., 2005a). Conversely, increases in aerobic fitness (Helgerud et al., 2001, Faude et al., 2014, Wells et al., 2014) and no change (Akubat et al., 2012, McMillan et al., 2005a) in aerobic fitness ($\dot{V}O_2$ max and S4) show equivocal aerobic adaptations to in-season training. Potential factors influencing these differences are the lower level fitness and a greater potential to improve which may be present during pre-season (McMillan et al., 2005a). Furthermore, a change in training focus in which technical and tactical aspects of performance are prioritised over physical performance (Gamble, 2006), players reaching a genetic ceiling or developing NFOR (Faude et al., 2014) in-season could account for these differences. As noted in section 2.3.1 aerobic fitness should not be a priority if players already have a high level of aerobic fitness enabling sufficient recovery from high intensity bursts. Thus, training should focus on improving anaerobic and neuromuscular performance, critical to high intensity actions during match play (Silva et al., 2015).

High intensity interval training (HIIT) consisting of high intensity runs of longer (2-4 min), and shorter (<45s) durations have been shown to improve aerobic fitness ($\dot{V}O_2$ max and lactate threshold), high intensity intermittent exercise performance (Yo-Yo IRT1) and neuromuscular performance (30 m sprint; Faude et al., 2014, Iaia et al., 2009, Wells et al., 2014). Manipulating exercise intensity, exercise duration and recovery duration of HIIT influence how the energy systems are taxed and the subsequent improvements in aerobic, anaerobic and neuromuscular performance (Buchheit and Laursen, 2013a, Buchheit and Laursen, 2013b). The development of physical capabilities in conjunction with the technical and tactical elements make football specific HIIT and small sided games (SSG) appealing to coaches. The use of football specific HIIT using technical dribbling tracks (Chamari et al., 2005, Hoff et al., 2002, McMillan et al., 2005b) and progressively overloaded SSG (Iaia et al., 2009, Owen et al., 2012) have shown increases in aerobic fitness in elite senior and elite youth football players.

SSG have been shown to be equally effective as HIIT in improving high intensity intermittent exercise performance (Yo-Yo IRT1) in elite junior football players (Hill-Haas et al., 2009, Impellizzeri et al., 2006). Junior players (< 16 yrs; $\dot{V}O_2$ max 56 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$ to 59 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$) tend to have lower aerobic fitness in comparison with U18 elite youth football players (57 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$ to 70 ± 7 $ml \cdot kg^{-1} \cdot min^{-1}$). Hence, the intensity of SSG may not be adequate to elicit improvements in aerobic fitness in youth players, particularly in those players with high levels of fitness (Hill-Haas et al., 2011). In addition, Ade et al., (2014) reported SSG were less physiologically taxing in comparison to HIIT and therefore the use of traditional HIIT in addition to SSG might further improve aerobic fitness, anaerobic energy turnover and neuromuscular function. Another potential limitation to SSG is the lack of an appropriate stimulus to improve neuromuscular performance (Ronnestad et al., 2011, Sporis et al., 2011). Strength and power training (e.g. resistance exercise and plyometrics) are required to improve and subsequently maintain neuromuscular performance in elite football players (Ronnestad et al., 2011, Silva et al., 2015). Hence, the concurrent application of football specific training modalities (e.g. SSG) and other training modalities (e.g. HIIT, plyometrics, resistance exercise) are required to optimise physical performance.

Integrating various training practices to optimise performance is difficult. Concurrent HIIT, strength, speed, technical and tactical training in elite youth and elite senior football players has consistently yielded improvements in aerobic fitness ($\dot{V}O_2$ max, lactate threshold and maximal aerobic speed; Helgerud et al., 2011, Lopez-Segovia et al., 2010, Wong et al., 2010) with a decrement, (Lopez-Segovia et al., 2010), maintenance (Helgerud et al., 2001) or improvement (Wong et al., 2010) in neuromuscular performance (CMJ and Sprints) reported. Hence, careful consideration is required when planning concurrent training modalities to ensure that aspects of physical performance are not compromised. Furthermore, the aforementioned individual factors (e.g. exposure, fitness, recovery) are difficult to account for when the majority of training is carried out as a team.

Therefore, monitoring assessments which give an insight into the training dose, the resultant stress, the time course of recovery and player fitness are likely to assist coaches and sport science practitioners in the intricate process of player management, therefore aiding the design of, and ability to adjust, training to facilitate optimal physical performance at both a team and individual level. The subsequent section discusses the monitoring assessments in detail.

2.5 Monitoring assessments

As discussed in sections 2.4.5, the training and competition demands placed upon youth players in the PDP could put players at risk of NFOR, reduced well-being and poorer football performance. Monitoring assessments can assist in player management if they can be applied frequently and provide immediate feedback that allows coaches to act upon the information immediately (Saw et al., 2016). These assessments need to identify the training dose, the time course of recovery and subsequent physical adaptation to allow coaches to make informed decisions on the appropriate frequency, intensity, duration and modalities of team training and whether training modification is required for any individual (Halson, 2014).

Several subjective and objective monitoring assessments have been proposed to identify the training dose, resultant stress and the time course of recovery (Halson, 2014). These include subjective questionnaires (Saw et al., 2016), performance tests (Halson, 2014), HR assessments (Buchheit, 2014), biochemical assessments (Halson, 2014), measures of the internal training dose (Akubat et al., 2012, Impellizzeri et al., 2004) and micro technology tracking systems (Aughey, 2011).

As discussed in section 2.4.6 it is the internal training load that ultimately dictates the training outcome or response. Therefore, it is necessary to identify the time course of recovery and fitness response following exposure to internal loads to assess how the player is coping with the current training periodisation, allowing intervention if training periodisation is not appropriate. Monitoring assessments which provide coaches and sport science practitioners with acute (daily) information are required in the immediate daily management of player training load. In addition, monitoring of short-term (1-8 weeks) and chronic (several months / seasonal) responses is necessary to detect NFOR and inform longer term training periodisation. In practice, implementing effective monitoring assessments in team sports is dependent on the human and financial resources available to collate, analyse, feedback and utilise the data in an appropriate timescale (Saw et al., 2015b).

2.5.1 Subjective well-being questionnaires

The use of subjective questionnaires as a monitoring assessment has recently received considerable attention (Gastin et al., 2013, Saw et al., 2015b, Saw et al., 2016, Thorpe et al., 2015, Thorpe et al., 2016). Subjective questionnaires assessing perceptions of mood state, behavioural symptoms and physical symptoms give a multidimensional assessment of physical and psychological constructs of well-being (Saw et al., 2016). Furthermore, the simplicity, low cost and utility make subjective measures an attractive monitoring tool (Halson, 2014).

A survey carried out to identify current training monitoring practices, used by sport science practitioners and coaches working with elite athletes (including elite football players) in New Zealand and Australia, reported the most popular assessment tool used was a subjective well-being questionnaire (Lee-Taylor et al., 2012). Eighty four percent of sport science practitioners and coaches used a well-being questionnaire to monitor athlete responses, with the majority (80 %) of the questionnaires used developed 'in-house' and consisting of 5-12 items. Well-being assessments were completed on either a daily (55 %), multiple occasions during the week (24 %), weekly (18 %) or monthly (2 %) basis. The widespread use of questionnaires developed 'in-house' likely reflects that these assessments are inexpensive and give real time feedback on each athlete's well-being which can assist the coach and sport science practitioner to make informed decisions with regard to training periodisation.

Section 2.4.2 highlighted a poorer physical performance may be more likely with a decrease in well-being however, well-being and physical performance were not inextricably linked. This does not render perceptions of well-being redundant in monitoring the athletes' acute (daily) short-term (1 to 8 weeks) and chronic adaptive (seasonal) responses. A reduction in well-being may influence other aspects of football performance and player development and coaches have a duty of care to ensure the well-being of elite youth players. Arguably, this highlights the need for a mixed methods monitoring approach.

The dose-response relationship between training dose and recovery is important with regard to effective training periodisation. Therefore, monitoring assessments are often validated based on their sensitivity to increased and reduced acute, short-term and chronic training loads (Saw et al., 2016). Subjective questionnaires are more sensitive to changes in acute (Thorpe et al., 2016) short-term and chronic training loads (Saw et al., 2016) in comparison with other objective measures (performance, physiological and biochemical indicators) in a range of athletic populations including elite youth and elite senior football players.

Although previously validated, the Recovery stress questionnaire for Sport (RESTQ-Sport; Kellman and Kallus, 2001), the profile of mood states (POMS; Morgan et al., 1987), the daily analysis of life stresses (DALDA; Rushall, 1990) and multicomponent measure of training distress (MTDS; Main and Grove, 2009) are lengthy and contain between 22 and 76 items. These subjective questionnaires may provide a more complete assessment of player well-being in comparison with shorter questionnaires (Saw et al., 2016). However, these subjective questionnaires may lack specificity to the sport (e.g. POMS) and are time consuming to fill-in which will reduce adherence, influence the honesty of the responses and take too long to analyse immediately to give timely feedback to the coach (Saw et al., 2015a). To overcome these limitations sports science practitioners have designed their own subjective questionnaires 'in-house' containing fewer items (3 to 9 items) that can be completed in less than 30 s on a daily basis (Gastin et al., 2013, Raines et al., 2012, Thorpe et al., 2015, Thorpe et al., 2016). These measures are cheap, cost effective and provide rapid feedback on training responses on a daily basis which the coach can act upon immediately, if necessary. Feedback can be monitored over short-term and chronic timescales which could assist in informing team and individual training periodisation over time (Saw et al., 2015a).

Several subjective questionnaires developed ‘in-house’ have been validated based on their sensitivity to acute and short-term training loads. Gastin et al., (2013) reported nine items of wellness (fatigue, muscle strain, quadriceps strain, hamstring strain, pain / stiffness, power, sleep quality, stress and well-being) were lower the day following an acute high match day load and higher the day following lower training loads in Australian Rules football players. Similar, findings have been reported in elite senior football players with a 35-40 % deterioration in perceptions of well-being (perceived sleep quality, muscle soreness and fatigue) evident a day following a competitive fixture with improved well-being associated with days following lower training loads (Thorpe et al., 2016). Hence, the temporal application of subjective questionnaires developed ‘in-house’ could provide valuable information on changes in player well-being, indicative of aspects of recovery. This information could be used to assist in the management of elite youth football players.

Saw et al., (2015a) investigated factors influencing the implementation of ‘in-house’ subjective questionnaires in an applied sport setting. Based on interviews with athletes, coaches and sport science and medicine practitioners, eight factors associated with the measure (mode, accessibility, compatibility, interface, question design factors and time burden, timing of completion and data analysis and output) and six factors associated with the social environment (athlete buy in, staff buy in, peer-influence, reminders, reinforcement and data security) were identified as key factors influencing the efficacy of subjective questionnaires in an applied sport setting. Therefore, effective subjective questionnaire implementation is dependent upon a multi-factor and multi-level approach which needs to ensure compliance, data accuracy and ultimately give valuable information on the athletes' well-being (Saw et al., 2015a).

As a result of the multi-factor and multi-level considerations in designing subjective questionnaires, a unique design may be required for different groups of athletes (Saw et al., 2015a). Hence, the selection of questionnaire items requires careful consideration. Questionnaire items (fatigue, muscle soreness sleep quality, stress and well-being) have been shown to be sensitive to acute daily increases and decreases in training load and competition load in elite senior football players (Thorpe et al., 2015, Thorpe et al., 2016) and other team sport players (Gastin et al., 2013). Additionally, the subscales of previously validated more lengthy questionnaires may be useful in the design of shorter bespoke subjective questionnaires. Investigating the association of previously validated questionnaire constructs such as the RESTQ-Sport (Kellmann and Kallus, 2001) and POMS (Morgan et al., 1987) could be of value with regard to the items used in a well-being questionnaire developed 'in-house'.

In a meta-analysis (56 original studies), Saw et al., (2016) reported vigour / motivation, physical symptoms/ injury, non-training stress, fatigue, physical recovery, general health and well-being and being in shape were sensitive to short-term increases and decreases in training load. In addition, non-training stress, fatigue, physical recovery, general health and well-being and being in shape were sensitive to chronic training loads. Hence, questions which relate to these subscales should be considered as promising questionnaire items when developing a questionnaire for use in an applied setting.

Questionnaire items which lacked sensitivity to short-term and chronic training loads were depression, confusion, sleep quality, emotional stress, social recovery and self-efficacy (Saw et al., 2016). In contrast, sleep quality has been reported to be sensitive to acute changes in daily training loads (Thorpe et al., 2016). These differences could be a result of differences in question type, the specific population and differences in the length of the training period assessed (acute vs. short term vs. chronic). In addition, items which are not sensitive to short-term and chronic loads such as loss of appetite and mood disturbances including depression (Kentta and Hassmen, 1998, Rushall, 1990, Urhausen and Kindermann, 2002,) may be sensitive to non-training stresses (Morgan et al., 1987, Urhausen and Kindermann, 2002) and therefore should not be discounted.

Based on the aforementioned literature, questionnaire items which consider motivation, sleep quality, recovery, appetite, fatigue, stress and muscle soreness could provide valuable information on player well-being, indicative of stress and aspects of recovery. Limiting the number of questions will allow simple assessments which can be carried out daily, but can also be collated over a longer time-course (Saw et al., 2015a). Hence, establishing the sensitivity of these psychobiological constructs of well-being to acute, short term and chronic training loads in elite youth footballers is necessary to identify the suitability of these assessments in enhancing player management and reducing the risk of NFOR.

2.5.2 Physical performance assessments

Lee-Taylor et al., (2012) reported that physical performance assessments were the second most commonly used assessments by coaches and sport science practitioners working with elite athletes in Australia and New Zealand, with 61 % of survey respondents using maximal or submaximal physical performance tests. These performance assessments were most commonly implemented on a weekly or monthly basis (64 %) with more frequent (e.g. daily or more than once a week) performance assessments less common (36 %). Maximal 'performance' or 'fitness' tests which replicate demands of the sport are considered to be the best indicator of the fitness fatigue dichotomy indicating FOR (Currell and Jeukendrup, 2008, Halson, 2014). In the literature, the terms performance and fitness tests are often used interchangeably. In the context of the present thesis the term performance tests will be used due to the influence of both fitness and fatigue on such assessments.

Given that football performance is multifactorial and based on combining technical, tactical and physical attributes (Section 2.2), attaining valid assessments of performance is challenging. Football-specific physical performance assessments can provide an objective measure of potential physical performance during match play (Buchheit, 2013, Mendez-Villanueva, Stolen et al., 2005, Rampinini et al., 2007a). This could assist in the selection of training modality, intensity and volume (Svensson and Drust, 2005) and the detection of acute physical fatigue and NFOR (Section 2.4; Halson, 2014). However, using these assessments on a regular basis is not feasible given that they may further exacerbate stress (Meeusen et al., 2013) Therefore, these assessments might assist in the short-term and chronic (>4 weeks) retrospective assessment of training periodisation but cannot be used to identify any acute daily changes in physical performance to inform immediate player management.

Laboratory and field physical performance tests, noted in section 2.3, are commonly employed by elite youth academies. These include assessments of aerobic fitness ($\dot{V}O_2$ max and S4; Akubat et al., 2012, McMillan et al., 2005a) high intensity intermittent exercise performance (Yo-Yo IRT1 and Yo-Yo IRTL2; Bangsbo et al., 2008) and neuromuscular performance (CMJ and sprints; Faude et al., 2014, Mendez-Villanueva and Buchheit, 2013, Sporis et al., 2010, Svensson and Drust, 2005). Field assessments appear to have greater utility in comparison with laboratory assessments when considering time and financial resources available in team sports (Svensson and Drust, 2005).

In contrast with the majority of maximal physical performance tests (e.g. $\dot{V}O_2$ max, Yo-Yo IRT1 and sprints), the use of CMJ performance has become a popular assessment to monitor physical recovery. The simplicity, minimal time burden and minimal impact on exacerbating fatigue (Twist and Highton, 2013) allow the temporal application of CMJ assessments across an acute, short-term and chronic timescale. In a fatigued state, it is proposed that the CMJ highlights that concentric and eccentric aspects of the stretch reflex are compromised as a result of metabolic fatigue, impaired excitation-contraction coupling and a reduction in muscle stiffness due to changes in stretch reflex sensitivity (Komi, 2000, Nicol et al., 2006). As identified in section 2.4.5 equivocal findings have reported a varied time-course of recovery in CMJ performance following competitive or simulated match play which could be influenced by several factors (e.g. magnitude of stress, fitness and recovery interventions). However, some of the discrepancies in the time-course of recovery in CMJ performance following match-play could reflect the validity of the assessment method used (Buckthorpe et al., 2012).

The force plate is considered the gold standard measure to assess CMJ performance (Buckthorpe et al., 2012) but the equipment is expensive and implementation requires a higher level of expertise, which is not likely to be available to category two, three and four football academies. Hence, the contact mat is often considered as an alternative option (Twist and Highton, 2013, Rollo et al., 2014). Validation studies have reported the criterion validity of the contact mat in assessing CMJ height was relatively poor (Buckthorpe et al., 2012, Garcia-Lopez et al., 2013), yet acceptable reliability (Garcia-Lopez et al., 2013) suggests that the contact mat may be useful to detect changes in neuromuscular performance over an acute, short-term and chronic timescale (Buckthorpe et al., 2012).

2.5.3 Submaximal physical performance assessments

Submaximal HR measures such as resting heart rate (HR_{rest}; Bosquet et al., 2008), resting HR variability (HRV; Plews et al., 2013), exercising heart rate (HR_{ex}) at a fixed submaximal intensity (Buchheit, 2014) and heart rate recovery (HRR) following exercise at a fixed submaximal intensity (Daanen et al., 2012) have been proposed as markers of fitness and physical recovery. These assessments reflect changes in the autonomic nervous system activity which may be indicative of the physical performance capability of a player (Aubry et al., 2015, Buchheit, 2014, Daanen et al., 2012). Submaximal HR assessments are low cost, non-fatiguing, simple to administer, have utility in large groups and have received considerable attention in team sports due to their potential to give feedback on levels of fitness and fatigue across acute, short-term and chronic timescales (Buchheit, 2014).

A reduction in HR_{ex} has been proposed as a measure of aerobic fitness (Buchheit, 2014). In addition, early studies reported that NFOR was associated with an increase in HR_{rest}, potentially due to an increase in sympathetic tone and / or a removal of parasympathetic tone (Dressendorfer et al., 1985, Israel, 1958, Kindermann, 1986, Kuipers and Keizer, 1988). More recently, a meta-analysis of 34 studies by Bosquet et al., (2008) revealed trivial differences in

HR_{rest} following two weeks or more of intensified training (Bosquet et al., 2008) suggesting HR_{rest} cannot be used to detect NFOR or OTS. However, the authors reported that intensified training over a shorter duration, of two weeks or less, was consistently associated with an increase in HR_{rest}. Therefore, HR_{rest} could detect acute physical fatigue and give valuable information with regard to the immediate management of elite youth football players.

During periods when HR remains constant, heart rate variability (HRV) assessed as the duration between R-R intervals can vary (Achten and Jeukendrup, 2003). HRV can be assessed at rest, during exercise and post exercise, however, resting HRV seems the most promising marker of cardiac autonomic nervous system function as HRV during and post-exercise are influenced by too many factors (e.g. environment, exercise intensity and breathing; Buchheit, 2014). An increase in HRV has been associated with improved aerobic fitness (Buchheit et al., 2010) with reductions in HRV reported in response to short-term intensified training and inadequate recovery (Iellamo et al., 2002, Manzi et al., 2009a). As with HR_{rest}, HRV may be useful in identifying acute physical fatigue but not NFOR or OTS. Bosquet et al., (2008) reported a moderate reduction in HRV following acute and short-term intensified training, but no changes in HRV in response to longer term intensified training. However, the lack of any change in HRV in response to longer term intensified training could reflect both the unique HRV responses of each individual and the complex interactions between training history, levels of fitness and fatigue over longer term training periods (Manzi et al., 2009a, Plews et al., 2013). Hence, acute daily monitoring assessed on longitudinal and individual bases, with context provided by other assessments, could assist in the assessment of fitness and fatigue of each player (Plews et al., 2013).

A range of submaximal physical performance tests which assess HR_{ex} at a fixed exercise intensity and HRR following the cessation of exercise (Buchheit et al., 2012, Lamberts et al., 2004) have been proposed as a monitoring assessment to track changes in fitness over weeks and months (Buchheit, 2014) and as marker of poor physical recovery (acute physical fatigue, NFOR and OTS; Achten and Jeukendrup, 2003). A reduction in HR_{ex} is concomitant with improvements in aerobic fitness in elite youth football players (Buchheit et al., 2012) but although a faster HRR has been reported following endurance training in untrained individuals (Yamamoto et al., 2001), HRR did not decrease in elite youth football players as aerobic fitness improved (Buchheit et al., 2012). The lack of sensitivity of HRR to changes in aerobic fitness might reflect the sensitivity of HRR to both changes in aerobic fitness and acute physical fatigue (Daanen et al., 2012). Equivocal responses to intensified training associated with acute physical fatigue and NFOR have reported an increase (Borresen and Lambert, 2007, Schmikli et al., 2011) and a decrease (Aubry et al., 2015, Lamberts et al., 2010) in both HRR and HR_{ex}. These differing HRR and HR_{ex} responses associated with acute physical fatigue and NFOR in addition to the influence of changes in fitness on HRR and HR_{ex} make using these measures to elucidate the fitness and fatigue response difficult but not redundant. When triangulated with other measures such as specific training phase (high load or low load), other performance assessments and subjective questionnaire responses, HR based measures such as HRR and HR_{ex} may provide a useful measure when considered in the context of the fitness and fatigue response (Aubry et al., 2015) in elite youth football players.

A limitation to HR assessment methods is their day to day reliability. Factors such as hydration, temperature, altitude, exercise intensity, diurnal variation and body position have been shown to influence day to day reliability of HR assessments (Achten and Jeukendrup, 2003, Al Haddad et al., 2011, Sandercock et al., 2005). A greater day to day reliability has been reported for HR_{ex} (CV: ~1 % to ~3 %) in comparison with HR_{rest} (CV: ~10 %), HRR (CV: ~2 % to ~25 %) or time domain measures of resting HRV (CV: 7.6 % and 12.6 % for ln rMSSD and lnSDNN, respectively; Al Haddad et al., 2011, Lamberts et al., 2004, Lamberts and Lambert, 2009). The reliability of HR assessments may impact upon the utility of these measures to assess individual players in an applied setting (See section 2.6).

In team sports it is proposed that resting HR and HRV measures are ideally carried out in a 5-10 min period in the morning prior to training whereas HR_{ex} and HRR assessments can be carried out during a warm up prior to the start of training (Achten and Jeukendrup, 2003, Buchheit, 2014). It is suggested that time domain indices such as ln rMSSD and lnSDNN are potentially the most useful tools in practice to measure autonomic control due to their compatibility with short duration recordings and low sensitivity to breathing patterns (Buchheit 2014, Plews et al., 2013a). However, given the variability of HRV assessments, measurements are required frequently (>3-4 times per week). This may be difficult to achieve in a team sport environment, hence a weekly assessment of HR_{ex} and HRR on a standardised day in a team setting during the warm up is the most viable option (Buchheit, 2014).

2.5.4 Biochemical markers

Several biochemical markers, including creatine kinase, testosterone, cortisol and salivary IgA, have been proposed as measures to assess FOR, NFOR and OTS (Halson, 2014, Meeusen et al., 2013). However, no single definitive biochemical marker has been identified (Halson, 2014). The most promising marker is creatine kinase which is indicative of muscle damage and responsive to short-term increases and decreases in training load (Saw et al., 2016).

However, the variability of creatine kinase is high and the temporal relationship between creatine kinase and perceptions of muscle soreness is poor (Twist and Highton, 2013). Other assessments such as testosterone, cortisol, salivary IgA are not sensitive to short-term or chronic changes in training load (Saw et al., 2016) and have a poor temporal relationship with performance (Twist and Highton, 2013). These aforementioned factors, in addition to the time burden, cost and expertise required to administer biochemical assessments, limit their utility in an applied team sport setting.

2.5.5 Assessment of internal load

As previously discussed in section 2.4.6 the training outcome is determined by the internal load. The use of HR monitors as a measure of exercise intensity is widespread in elite youth football (Akubat et al., 2012, Impellizzeri et al., 2004). HR during training and match play may give an accurate reflection of the total internal physical dose to which players are exposed (Akubat et al., 2012).

Two key factors influencing the internal training load are the duration and intensity of exercise. HR accurately reflects the aerobic energy demands ($\dot{V}O_2$; Esposito et al., 2004, Hoff et al., 2002) but may underestimate the anaerobic energy demands of football specific high intensity intermittent exercise (Tumilty, 1993). Therefore, a weighting factor based on the blood lactate response which accounts for the exponential increase in energy demand at higher exercise intensities is required to more accurately assess the training dose (Akubat et al., 2012). The 'training impulse' (TRIMP) was developed by Bannister (1975) in which the duration of exercise is multiplied by mean HR and a weighting factor based on a generic blood lactate response (Bannister's TRIMP, bTRIMP). Valid assessments of training load must be sensitive to changes in fitness and fatigue. As noted in section 2.4.6 Bannister (1975) successfully used fitness and fatigue responses to the TRIMP to predict endurance performance.

A limitation to the bTRIMP is that the use of mean HR may underestimate the intensity of high intensity intermittent exercise. In endurance exercise where HR remains relatively constant the use of mean HR is representative of overall exercise intensity (Morton et al., 1990). However, the stochastic nature of high intensity intermittent exercise results in a greater fluctuation in HR and mean HR does not reflect exercise intensity (Drust et al., 2000). To counteract the limitation of using mean HR, Edwards TRIMP (Edwards 1993) and Lucia TRIMP (Lucia et al., 2003) were developed with weighting zones in which the more frequent sampling of HR (~every 5 s) was multiplied by a weighting factor based on zones (e.g. 1 to 5) and summated to provide a TRIMP. However, the weightings used were arbitrary (e.g. 1 to 5) and fail to reflect the exponential physiological response evident with increasing exercise intensity. Another limitation to Edwards TRIMP and Lucia TRIMP is they have not been validated to show a dose response with fitness or fatigue.

More recent studies have attempted to address these limitations. Stagno et al., (2007) based the weighting values for a five zone method on mean blood lactate values in eight hockey players (Team TRIMP). A dose response relationship between the weekly Team TRIMP and both S4 (r=0.67, *P*=0.04) and $\dot{V}O_2$ max (r=0.65, *P*=0.04) was evident over an eight week training period. However, limitations to the Team TRIMP were still evident. Team TRIMP like bTRIMP uses a generic weighting factor which is not based on the individual's physiological response which as noted in section 2.4.6 is a key component of internal load. Furthermore, creating weighting zones might be limited in that players exercising in the upper and lower limits of a zone are given the same weighting.

To remove these limitations the iTRIMP was developed (Akubat et al., 2012, Manzi et al., 2009b). iTRIMP is individualised based on the individual HR – blood lactate profile with the weighting factor applied and summated each time HR is sampled (Manzi et al., 2009b). Several studies have reported a strong association between the iTRIMP method and changes in aerobic fitness in elite youth players (r=0.67; Akubat et al., 2012) and elite senior players (r=0.64; Manzi et al., 2013). To date, only one study has attempted to validate various HR based methods (Akubat et al., 2012). Akubat et al., (2012) observed iTRIMP had a stronger correlation (r=0.67) with changes in aerobic fitness than did bTRIMP (r=0.20) and the Team TRIMP (r=0.28).

A limitation to the iTRIMP method is the need for laboratory testing, which in team sports has time burden and cost implications. To alleviate these issues associated with iTRIMP, several clubs use HR assessments which assess time spent in zones or zoning methods based on arbitrary weightings which do not require a laboratory test and extensive analysis to calculate daily internal load. Data from elite senior players has indicated that time spent above S4 has a strong association with changes in aerobic fitness following a five week pre-season training period (Castagna et al., 2011; Impellizzeri et al., 2005). Therefore, the use of the more time consuming iTRIMP method may not be necessary. A more thorough comparison of the validity of HR methods is required to establish which of these methods should be used to assess internal training load in elite youth footballers.

A limitation to HR based methods is that they fail to quantify the high intensity neuromuscular training loads players are exposed to (Little and Williams, 2007). The rate of perceived exertion (RPE) has previously been identified as a good marker of exercise intensity (Borg, 1982) and has been associated with HR (r=0.60) and blood lactate (r=0.63) during football specific exercise (SSG; Coutts et al., 2009). Session RPE (sRPE) which combines RPE with the duration of exercise session has been proposed as a global indicator of training load (Impellizzeri et al., 2005). A limitation to sRPE as a measure of internal training load is it is often validated against HR based measures (Alexiou and Coutts, 2008, Impellizzeri et al., 2004) and not dose-response relationships where sRPE has been shown to have a weaker association with changes in aerobic fitness when compared with the iTRIMP method (Akubat et al., 2012).

It is noted that sRPE could provide additional information with regard to the high intensity efforts in football which HR based methods may fail to quantify (Alexiou and Coutts, 2008). Recently, differential RPE (dRPE), which assesses perceptions of how hard the session was on a players legs [muscular RPE (mRPE)] and how hard the session was on a players chest [respiratory (rRPE)], could assist in dichotomising the aerobic and neuromuscular training and competition loads (Weston et al., 2015). mRPE (r=0.69) and rRPE (r=0.71) have shown large and very large relationships with changes in aerobic fitness in non-elite and elite youth football players (Gil-Rey et al., 2015). However, small to trivial relationships (r=-0.21 to 0.25) between rRPE, mRPE and changes in neuromuscular performance have been reported (Gil-Rey et al., 2015). The lack of a dose response relationship suggests dRPE may be unable to sensitively track improvement in neuromuscular performance. A decision was taken, in the present thesis, to use HR based assessments of training. In practice, using a single measure to quantify training load is attractive however the limitations of this approach are discussed in section 7.1.

The monitoring of external training load using player tracking systems gives valuable information with regard to the work completed in training and match play activities (Aughey, 2011, Akubat et al., 2014, Gaudino et al., 2015). An understanding of the work completed by each player is important and if used concurrently with a measure of internal load it could be used to guide training prescription (Halson, 2014, Weston et al., 2015). However, player tracking technology is expensive which might limit its availability in category two, three and four academies. In a practical setting, measures of internal training load in addition to well-being and performance assessments which assess the response to the internal training load could provide valuable information to the sport science practitioner and the coach with regard to player management.

2.6 Assessing individual changes

Individual characteristics will influence the training response and are dependent on numerous factors including initial level of fitness, genetics, recovery and training exposure (section 2.4.4). Therefore, in a practical setting, an individual approach to analysing and reporting athlete responses to training needs to be considered. To assess individual changes in objective performance tests, the uncertainty or 'noise' in the measurement and the smallest practically important effect termed 'the smallest worthwhile change' (SWC) need to be considered to identify if the change is meaningful (Batterham and Hopkins, 2006). Hopkins (2004) proposed a statistical approach to assessing individual changes calculating the likelihood of an individual's change based upon the probability of whether the observed change 'signal' is larger than the typical error ('noise') and the SWC. This method has advantages over previously proposed Z scores (Pettitt, 2010) as it attempts to acknowledge the uncertainty of the measure and quantify what constitutes a meaningful change.

Typical error (TE) is the most useful measure of reliability due to its analytical potential in calculating the likelihood of change in individual player performance (Hopkins, 2000). Reliable tests are important as they dictate the magnitude of the change which can be detected. For example a 2.5 % improvement in a performance test with a TE of 1.0 % and a SWC of 1.0 % would be considered a meaningful change. Conversely, a 2.5 % improvement in a performance test with a TE 2.0 % and a SWC of 1.0 % would be considered unclear (Hopkins, 2004). A limitation to the use of TE is that it represents the group variation in a test, not that of the individual. Establishing the normal variation for an individual is challenging in an applied setting, due to difficulties in attaining repeated measures, hence the TE is often considered as an appropriate alternative. Furthermore, time and logistics influence whether a TE can be attained in the group of athletes a sports science practitioner is working with in an applied setting. For assessments where it is difficult to establish a TE, Hopkins (2004) recommended using the TE established in previous studies in a similar population.

Determining what constitutes the SWC is challenging (Hopkins, 2004). In individual sports where the performance outcome is measurable, the SWC is easier to define. Hopkins (2004) identified that a 0.3 % improvement would give an elite 100 m sprinter an additional medal once in every 10 races. In team sports defining the smallest worthwhile change can be complex given physical performance tests are not clearly related to the performance outcome of a match (Hopkins, 2004). Hence, it has been proposed that in team sports a Cohen's standardised difference of 0.2 (Hopkins, 2004) or 0.25 (Taylor et al., 2010) of the between participant standard deviation is an appropriate arbitrary SWC value.

The limitations to these methods are discussed further in section 7.1. However, this approach, based on scientific principles which attempt to acknowledge the uncertainty of the measure and what constitutes a meaningful change, is a progression in elite youth football where these factors are seldom considered. Unfortunately, the use of statistical approaches such as the likely limits is not feasible with subjective well-being assessments due to the data being ordinal. However, sport science practitioners must endeavour to establish a threshold to determine whether a change is meaningful in an applied setting (Hopkins, 2004).

2.7 Summary of literature review

In summary, the high training and competition loads elite English youth players are exposed to may result in a reduction in well-being and impaired physical performance. Monitoring assessments indicative of changes in physical performance, training stress and associated recovery may assist in player management strategies which inform training periodisation and ultimately enhance the development of elite youth football players. These assessments must be aligned to human and financial resources available to a category two academy enabling the sport science practitioner to collate, analyse, feedback and utilise the data in an appropriate timescale. The reliability and validity of monitoring assessments and their temporal application in the management and development of elite youth football players (U18) at a category two academy are investigated in this thesis.

CHAPTER 3

3.0 General methods

Chapter three describes the subjective (WQ) and objective monitoring (maximal performance tests and HR assessments) assessments used in subsequent studies. The chapter also contains three pilot studies: 1) The reliability and selection of questionnaire items developed by the sport science practitioner at the football club; 2) The reliability and smallest worthwhile change of several objective monitoring strategies; 3) The validity of quantifying training load using various HR based methods.

3.1 Ethical approval

All studies were approved by the Coventry University Ethics committee and conformed to the declaration of Helsinki (Appendix 1). All participants provided written informed consent after reading a specific participant information sheet (Appendix 2, Appendix 3). Parental informed consent was also obtained for participants under the age of 18.

3.2 Anthropometrics

Anthropometrics were assessed using the protocols set out by The International Society for the Advancement of Kinanthropometry (ISAK, 2001). Height was assessed using a stadiometer (Seca, UK). Body mass was measured using digital scales (Seca, UK). Skinfolds at 8 sites (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf) were measured using callipers (Harpenden, UK). All eight skinfold sites were measured in succession. This was completed three times with no time delay between each measurement cycle and the median of the three values for each skinfold site were summated to give a total skinfold value.

3.3 Subjective monitoring assessment

3.3.1 Well-being questionnaire (WQ)

The WQ has been used and developed by the sport science practitioners at the club since 2010 as a performance management tool to assess player well-being. The questionnaire items were selected based on areas considered by the sport science staff to be necessary in player management and by items in the literature frequently associated with athlete monitoring and NFOR (Coutts et al., 2007b, Kellmann and Kallus, 2001, Kentta and Hassmen, 1998, Morgan et al., 1987, Rushall, 1990). Participants were asked to rate their perceptions of well-being related to: motivation to train, quality of previous night's sleep, quality of recovery from previous day, appetite, feeling of fatigue, level of stress and level of muscle soreness (Raines et al., 2012) each on a Likert bipolar seven point scale [very good (+3), normal (0) to very poor (-3)]. The design of the WQ using a Likert bi-polar scale was originally selected by the sport science practitioners at the club to allow verbal anchors to be considered on a positive and negative scale. In an applied setting, where retrospective data is not always available, comparing their current well-being to normal was considered the most appropriate approach (Rushall, 1990). A full version of the questionnaire is available in Appendix 4 with the definitions of each questionnaire item in Appendix 5. For the purpose of analysis, the questionnaire items fatigue, stress and muscle soreness were reverse scored. Therefore a higher score reflected greater fatigue, stress or muscle soreness.

3.4 Objective monitoring assessments

3.4.1. Incremental treadmill test

A modified incremental treadmill test to determine peak oxygen uptake ($\dot{V}O_2$ peak), maximal aerobic speed (MAS), speed at a fixed blood-lactate concentration of 2 $mmol{\cdot}l^{-1}$ (S2) and speed at a fixed blood-lactate concentration of 4 mmol·l^{-1} (S4) was carried out on a motorised treadmill (HP Cosmos Saturn, Traunstein, Germany). The treadmill was set at a gradient of one percent to reflect the energetic cost of running outside (Jones and Doust, 1996). The protocol used was similar to the procedures suggested by Manzi et al., (2009b). The protocol consisted of five submaximal running stages at 6, 8, 12, 14 and 16 km·hr^{-1} with a one minute recovery between each bout. Once the participant had completed all submaximal running stages the treadmill speed was increased by 0.5 km·hr^{-1} every 30 s until exhaustion. A fingertip capillary blood sample was taken between each submaximal running stage and 3 min after exhaustion in the maximal incremental test. Capillary blood was collected in a heparinised 20 µl end to end capillary tube and transferred to an Eppendorf tube prefilled with 1ml of haemolysing solution (EKF Diagnostics, Madgeburg, Germany). The Eppendorf tube was closed, shaken gently and left for analysis immediately after each sample was collected. HR was recorded throughout the test using a HR monitor (Polar Team 2, Polar Electro, OY, Finland) and the highest HR attained during the test was taken as maximum HR (HR_{max}) for the participant being tested.

3.4.1.1 Determination of peak oxygen uptake ($\dot{V}O_2$ peak)

Oxygen uptake ($\dot{V}O_2$) during the incremental exercise test was measured using an online gas analyser (Cortex Metalyser 3B, Leipzig, Germany). Participants wore a facemask and mouthpiece fixed to a head cap which was connected to the gas analyser to enable $\dot{V}O_2$ to be calculated on a breath by breath basis. Participants ran until volitional exhaustion. Peak oxygen uptake ($\dot{V}O_2$ peak) was taken as an average of the final 30 seconds of exercise. Prior to testing, the laboratory conditions (ambient temperature and humidity) were input into the software. On a daily basis a three litre syringe was used to calibrate the volume transducer using five valid strokes. A two point gas calibration was performed daily prior to each test. The gas analyser was calibrated using a known concentration of gases (5 % O_2, 15 % CO_2, balance N_2; BOC Gases, Guildford, UK).

3.4.1.2 Determination of maximal aerobic speed (MAS)

MAS was determined as the final running speed attained for a minimum of 30 s during the incremental exercise test.

3.4.1.3 Lactate analysis

Blood lactate (BLa) concentration was measured using an automated analyser (Biosen C-line, Sport, EKF Diagnostics, Magdeburg, Germany). Analysis was based on an electro-chemical principle using a chip sensor. An automated sample was collected by the analyser from the Eppendorf tube. Following the measurement of each sample, the chip sensor was automatically cleaned. BLa was measured to a precision of 0.01 $mmol \cdot l^{-1}$. BLa was plotted against running speed and S4 was determined using exponential interpolation (Manzi et al., 2009b). S4 is the most frequent method used to assess changes in aerobic performance and S4 measures have been previously used to track changes in aerobic performance following training interventions in elite youth football players (Akubat et al., 2012, Faude et al., 2009, Manzi et al., 2013; McMillan et al 2005).

3.4.2 Sprint speed

Participants performed three maximal 30 m sprints (Shalfawi, et al., 2011). Sprint time was recorded using electronic timing gates (Smartspeed, Fusion Sport, Canberra, Australia). The start line was set 0.5 m behind the first set of timing gates. Each sprint was interspersed with a four minute passive recovery period. The fastest time achieved of the three sprints was used for analysis.

3.4.3 Countermovement jump (CMJ)

Following a set of three warm up jumps, participants performed three unloaded CMJ (Rollo et al., 2014). Jump time was measured using flight time and a contact mat and was used by the software to calculate jump height (Fusion Sport, Canberra, Australia). There was a 3-5 second intermission between each of the three jumps. The player was instructed to jump as high as possible and no information regarding jump technique was given. The highest jump was used in the analysis. Jumps were disqualified if either; 1) a player pulled their thighs up to their chest to extend their flight time; or 2) both feet did not land back on the jump mat. If a jump was disqualified, corrective feedback was given and the player performed another jump. If corrective feedback was provided, a longer intermission of 15-20 seconds was required between jumps.

3.4.4 Arrowhead Agility Test (AAT)

Participants completed the AAT (Chan and Chan, 2010; Harsley et al., 2014, Figure 3.1) as quickly as possible in the sequence ABCEA on two occasions and the sequence ABDEA on two occasions. Each run was inter-dispersed with a four minute standing passive recovery period. Electronic timing gates were used to record the time taken to run the agility course (Smartspeed, Fusion Sport, Canberra, Australia). The start line was set up 0.5 m behind the electronic timing gates. The run was disqualified if the player: 1) touched any of the cones; or 2) stepped over or failed to go around any of the cones; or 3) completed the course in a different order to that which was instructed. If a player was disqualified, corrective feedback was given and they performed the test again following a four minute recovery period. The fastest time achieved of the four runs was used for analysis.

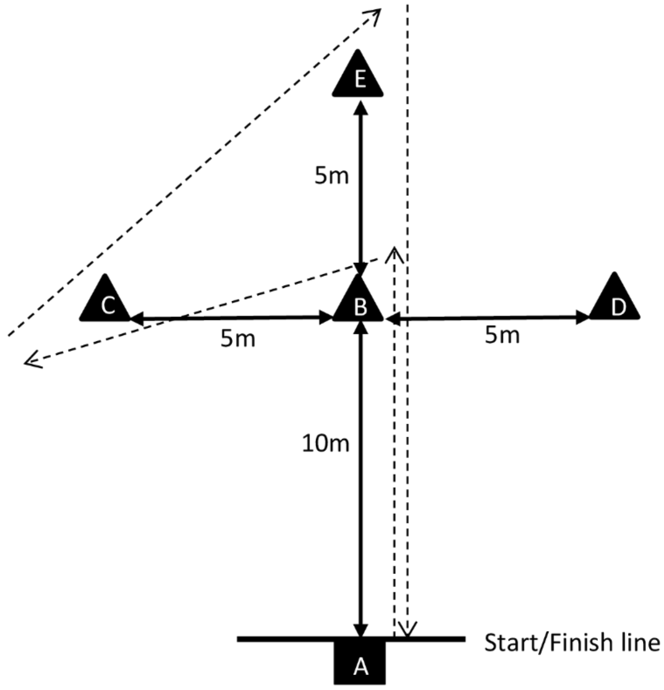


Figure 3.1. The arrowhead agility test (AAT) course. Participants began the test on the start line and ran in the sequence ABCEA shown by . The second run was similar and followed the sequence ABDEA which is not shown in this Figure. Distance is shown in meters between each of the cones.

3.4.5. Yo-Yo intermittent recovery test level 1 (Yo-Yo IRT1)

The Yo-Yo IRT1 was set up as described by Krustrup et al., (2003). To prevent players running prior to the audio beep, players were informed that the consequence of false starting on three occasions was withdrawal from the test.

3.4.6 Resting HR (HR$_{rest}$) and Heart rate variability (HRV)

Participants laid supine for 10 min. It was requested they stayed as still and as relaxed as possible and refrained from talking throughout. No attempt was made to control for breathing. A HR monitor (Suunto, Vantaa, Finland) was worn by participants across the chest and beat to beat HR was measured. The lowest HR in the final five minutes was used to determine HR_{Rest}. In addition, the final five min was analysed using Kubios software version 2.1 (University of Eastern Finland, Koupio, Finland). Time domain measures [the natural logarithm of the standard deviation of R-R intervals (ln SDNN) and the natural logarithm of the root square of the mean squared differences of successive R-R intervals (ln rMSSD)] were reported. These time domain measures were selected based on their compatibility with short duration recordings and low sensitivity to breathing patterns (Section 2.6.3).

3.4.7 Sub-maximal physical performance assessments

Sub-maximal HR was assessed using the heart rate interval monitoring system (HIMS; Lamberts et al., 2004). The test was 13 min in duration and consisted of four cycles of two min running interspersed with a one min recovery period following the first three stages and a two minute recovery period following the final stage. Participants were required to run between two 20 m lines at the speed dictated by audible bleeps timed to coincide with participants reaching each 20 m line (CD sound system, Bose, UK). Running speed was progressively increased at the beginning of each new cycle by 1.2 $km \cdot h^{-1}$. The running speed in the four cycles was 8.4 $km \cdot h^{-1}$, 9.6 $km \cdot h^{-1}$, 10.8 $km \cdot h^{-1}$ and 12.0 $km \cdot h^{-1}$, respectively. Following each stage, participants were requested to stand still and refrain from talking and stretching throughout the recovery period. A HR monitor (Suunto, Vantaa, Finland) was worn by participants around the chest and measured HR at 10 second intervals. HR_{ex} during each exercise stage was calculated as the peak HR during the final 30 seconds of each stage. HRR was determined by subtracting the resting HR obtained during the recovery period. HRR was also expressed as a percentage (% HRR) of HR_{ex}.

3.5 Pilot study 1: reliability and development of well-being questionnaire

3.5.1 Introduction

Subjective questionnaires developed 'in-house' by sport science practitioners could provide valuable information to assist in the management of elite youth football players (section 2.5). Kellmann and Kallus (2001) suggested a valid questionnaire should produce an internal consistency greater than Cronbach's α 0.7 providing relatively stable results on a daily basis. Furthermore, if associations between previously validated questionnaires (e.g. RESTQ-Sport, POMS) and the WQ could be established then this might indicate that WQ items could be used to assess aspects of well-being. The aim of the pilot study was to assess the reliability of the WQ developed by the sport science practitioners at the club and assess whether there were any associations between previously validated questionnaire items and the items in the WQ.

3.5.2 Methods

3.5.2.1 Participants

Thirteen high intensity intermittent team sport players (7 rugby players, 6 football players) from a college academy volunteered and provided informed consent for the study (mean ± SD: age 18 ± 1 yrs, stature 179 ± 6 cm, body mass 81.9 ± 18.6 kg). The participants' normal training involved three to four sessions per week plus a competitive match.

3.5.2.2 Study Design

The WQ (Section 3.3.1.), RESTQ-Sport and POMS were administered at 9.00 AM in the same order on three separate days during a five day period. The five day period was a low training load week in which no training or matches except for the additional monitoring assessments (see pilot study 3.6) were undertaken. Participants were asked to refrain from carrying out any ad hoc personal training sessions and asked to complete an activity diary (See Appendix 6) each day prior to testing. Participants did not report any additional training in the activity diary. All participants were familiarised with each questionnaire prior to its administration. Paper copies of each questionnaire were used throughout and individually completed by hand using a pen. Each questionnaire was completed in private out of view of other participants.

3.5.2.3 Recovery-stress questionnaire for sport (RESTQ-Sport)

The RESTQ-Sport as described by Kellmann and Kallus (2001) was completed by each participant. In brief, the questionnaire includes 76 questions with four questions for each of the 19 scales. Participants were asked to rate each question on a seven point scale (0 never, 1 seldom, 2 sometimes, 3 often, 4 more often, 5 very often, 6 always). The questionnaire took approximately 10 minutes to complete.

3.5.2.4 The profile of mood states (POMS)

The POMS (McNair et al., 1971), containing 65 items, was competed by each player. Questionnaire items corresponding to six scales were rated on a five point scale (0 not at all, 1 a little, 2 moderately, 3 quite a bit, 4 extremely). The questionnaire took approximately 10 minutes to complete.

3.5.2.5 Statistical analysis

The Shapiro-Wilk test was applied to the data in order to assess for a normal distribution. The data were not normally distributed and therefore appropriate statistical approaches were applied accordingly. Analysis of internal consistency of WQ, RESTQ-Sport and the POMS across the three trials was assessed using Cronbach α. The association between questions in the WQ and scales in both the RESTQ-Sport and the POMS in trial three were assessed using a correlation coefficient with 95 % confidence intervals (95 % CI). Effect sizes for correlation coefficients were used as qualitative descriptors, as described by Hopkins et al., (2009): trivial (<0.09); small (0.10-0.29); moderate (0.30-0.49); large (0.50 to 0.69); very large (0.70 to 0.89); nearly perfect (0.90 to 0.99); and perfect (1.00). All analysis was performed using Statistical Package for Social Science (SPSS) for Windows (version 20; SPSS inc, Chicago, USA).

3.5.3 Results

3.5.3.1 Questionnaire internal consistency

Five items on the WQ had an internal consistency greater than α 0.7 (range: 0.71-0.93; Table 3.1). Two items recovery and fatigue had an internal consistency lower than α 0.7 (Table 3.1). Recovery and fatigue both improved from trial 1 to trial 3 (0.31 ± 1.38 AU vs 1.08 ± 1.12 AU and -0.08 ± 1.55 AU to -0.62 ± 1.26 AU for recovery and fatigue, respectively). All RESTQ-Sport scales and POMS scales had internal consistency greater than α 0.7 (α 0.81-0.97 and α 0.82-0.98 for RESTQ-Sport scales and POMS scales, respectively, table 3.2 and table 3.3).

Table 3.1. Day to day trial mean and internal consistency for the seven items of the well-being questionnaire (WQ).

Item	Trial 1 mean	Trial 2 mean	Trial 3 mean	Cronbach α
Motivation	1.00 ± 1.00	1.00 ± 1.22	1.23 ± 1.30	0.78
Sleep quality	1.23 ± 0.93	1.15 ± 1.41	0.54 ± 1.33	0.71
Recovery	0.31 ± 1.38	1.08 ± 1.19	1.08 ± 1.12	0.62
Appetite	1.08 ± 1.38	1.23 ± 1.17	1.31 ± 1.32	0.82
Fatigue	-0.08 ± 1.55	-0.08 ± 1.19	-0.62 ± 1.26	0.65
Stress	-0.08 ± 1.04	0.15 ± 1.72	-0.08 ± 1.44	0.93
Muscle soreness	0.00 ± 1.63	-0.77 ± 1.42	-0.69 ± 1.38	0.77

Data expressed as mean ± SD. Internal consistency assessed using Cronbach's α.

Table 3.2. Day to day trial mean and internal consistency for the 19 scales on the recovery-stress questionnaire for sport (RESTQ-Sport).

Scale	Trial 1 mean	Trial 2 mean	Trial 3 mean	Cronbach α
General stress	0.52 ± 0.88	0.46 ± 0.68	0.63 ± 0.98	0.95
Emotional stress	1.17 ± 1.05	0.96 ± 0.89	0.90 ± 1.06	0.97
Social stress	1.38 ± 0.97	1.19 ± 1.15	1.48 ± 1.18	0.92
Conflicts / pressure	1.92 ± 0.99	1.48 ± 0.75	1.60 ± 0.90	0.91
Fatigue	1.44 ± 0.72	1.46 ± 0.73	1.50 ± 1.07	0.87
Lack of energy	1.44 ± 1.06	1.19 ± 0.82	1.37 ± 1.10	0.91
Physical complaints	1.58 ± 1.03	1.17 ± 1.00	1.15 ± 1.03	0.95
Success	3.21 ± 0.75	2.81 ± 0.77	3.00 ± 0.80	0.87
Social recovery	4.02 ± 1.14	3.92 ± 0.96	3.85 ± 1.02	0.84
Physical recovery	3.37 ± 0.95	3.13 ± 1.00	3.21 ± 1.22	0.92
General well-being	3.35 ± 0.75	3.44 ± 0.82	3.19 ± 0.85	0.81
Sleep Quality	4.21 ± 1.15	3.85 ± 1.20	3.77 ± 1.10	0.90
Disturbed breaks	1.12 ± 0.95	0.94 ± 0.65	0.98 ± 0.91	0.90
Emotional exhaustion	1.06 ± 0.78	1.08 ± 0.81	0.90 ± 0.81	0.96
Injury	2.19 ± 1.21	2.02 ± 1.31	2.19 ± 1.16	0.92
Being in shape	3.40 ± 1.09	3.48 ± 0.98	3.21 ± 0.78	0.85
Personal accomplishment	2.87 ± 1.13	2.88 ± 1.36	2.83 ± 1.45	0.94
Self-efficacy	3.42 ± 1.02	3.23 ± 0.91	3.29 ± 0.98	0.90
Self-regulation	3.60 ± 1.39	3.35 ± 1.20	3.21 ± 1.29	0.88

Data expressed as mean ± SD. Internal consistency assessed using Cronbach's α.

Table 3.3. Day to day trial mean and internal consistency for the six scales on the profile of mood states (POMS).

Item	Trial 1 mean	Trial 2 mean	Trial 3 mean	Cronbach α
Anger	0.44 ± 0.53	0.44 ± 0.61	0.44 ± 0.61	0.98
Fatigue	0.74 ± 0.75	0.57 ± 0.55	0.52 ± 0.64	0.87
Vigour	2.21 ± 0.72	2.31 ± 0.60	2.17 ± 0.78	0.82
Depression	0.29 ± 0.49	0.20 ± 0.42	0.19 ± 0.45	0.98
Tension	0.51 ± 0.66	0.44 ± 0.49	0.50 ± 0.69	0.95
Confusion	0.85 ± 0.72	0.56 ± 0.38	0.64 ± 0.66	0.90

Data expressed as mean ± SD. Internal consistency assessed using Cronbach's α.

3.5.3.2 Questionnaire associations

Associations between the WQ items and RESTQ-Sport scales ranged from 0.02 to 0.86 (Table 3.4). Similar items and scales produced low correlation coefficients. The association between fatigue in the WQ and RESTQ-Sport was moderate (r=0.39; Table 3.4). In comparison, the RESTQ-Sport scales such as lack of energy (r=0.60) and physical complaints (r=0.56) had a large association with the WQ fatigue item (Table 3.4). Correlation coefficients between items in the WQ and POMS scales ranged from small to very large (r=0.22 to r=0.77, Table 3.5). The large association between the fatigue scale in the POMS and the fatigue item in the WQ (r=0.62) was greater than the moderate association (r=0.39) between the fatigue scale in the RESTQ-Sport and the fatigue item in the WQ (Table 3.5).

Table 3.4. Association between the recovery-stress questionnaire for sport (RESTQ-Sport) and the well-being questionnaire (WQ).

	WQ questionnaire						
RESTQ-Sport scales	Motivation	Sleep Quality	Recovery	Appetite	Fatigue	Stress	Muscle soreness
General stress	-0.58 (-0.86 to -0.04)	-0.63 (-0.88 to -0.12)	-0.68 (-0.90 to -0.21)	-0.70 (-0.88 to -0.24)	0.63 (0.12 to 0.88)	0.42 (-0.17 to 0.79)	0.58 (0.04 to 0.86)
Emotional stress	-0.65 (0.15 to 0.88)	-0.66 (0.17 to 0.89)	-0.72 (-0.91 to -0.28)	-0.80 (-0.94 to -0.45)	0.62 (-0.87 to -0.11)	0.35 (-0.91 to -0.28)	0.44 (-0.25 to 0.76)
Social stress	-0.54 (-0.84 to -0.02)	-0.62 (-0.87 to -0.11)	-0.79 (-0.93 to -0.42)	-0.69 (-0.90 to -0.22)	0.51 (-0.06 to 0.83)	0.34 (-0.26 to 0.75)	0.59 (0.06 to 0.86)
Conflicts / pressure	-0.36 (-0.76 to 0.24)	-0.12 (-0.63 to 0.46)	-0.42 (-0.79 to 0.17)	-0.55 (-0.85 to 0.00)	0.50 (-0.07 to 0.82)	0.41 (-0.18 to 0.78)	0.28 (-0.32 to 0.72)
Fatigue	-0.48 (-0.82 to 0.10)	-0.51 (-0.83 to 0.06)	-0.75 (-0.92 to -0.34)	-0.67 (-0.89 to -0.19)	0.39 (-0.21 to 0.78)	0.42 (-0.17 to 0.79)	0.51 (-0.06 to 0.83)
Lack of energy	-0.69 (-0.90 to 0.22)	-0.61 (-0.87 to -0.09)	-0.72 (-0.91 to -0.28)	-0.66 (-0.89 to -0.17)	0.60 (0.07 to 0.87)	0.61 (0.09 to 0.87)	0.66 (0.17 to 0.89)
Physical complaints	-0.45 (-0.80 to 0.13)	-0.60 (-0.87 to -0.07)	-0.79 (-0.93 to 0.42)	-0.64 (-0.88 to -0.14)	0.56 (0.01 to 0.85)	0.46 (-0.12 to 0.80)	0.52 (-0.04 to 0.83)
Success	-0.04 (-0.58 to 0.53)	-0.14 (-0.64 to 0.45)	0.09 (-0.49 to 0.61)	0.02 (-0.54 to 0.57)	0.21 (-0.09 to 0.87)	-0.45 (-0.80 to 0.13)	-0.27 (-0.72 to 0.33)
Social recovery	-0.32 (-0.74 to 0.28)	0.10 (-0.48 to 0.62)	-0.12 (-0.63 to 0.46)	-0.07 (-0.60 to 0.50)	0.44 (-0.15 to 0.80)	-0.04 (-0.58 to 0.52)	0.16 (-0.43 to 0.65)
Physical recovery	0.45 (-0.13 to 0.80)	0.57 (0.03 to 0.85)	0.56 (0.01 to 0.85)	0.53 (-0.03 to 0.84)	-0.23 (-0.69 to 0.37)	-0.61 (-0.87 to -0.09)	-0.52 (-0.83 to 0.04)
General well-being	-0.08 (-0.60 to 0.49)	0.20 (-0.39 to 0.68)	0.14 (-0.45 to 0.64)	0.13 (-0.45 to 0.64)	0.04 (-0.52 to 0.58)	-0.43 (-0.79 to 0.16)	-0.30 (-0.73 to 0.30)
Sleep Quality	0.58 (0.04 to 0.86)	0.52 (-0.04 to 0.83)	0.63 (0.12 to 0.88)	0.62 (0.11 to 0.87)	-0.46 (-0.81 to 0.12)	-0.59 (-0.86 to -0.06)	-0.64 (-0.88 to -0.14)
Disturbed breaks	-0.45 (-0.80 to 0.14)	-0.37 (-0.77 to 0.23)	-0.72 (-0.91 to -0.28)	-0.67 (-0.89 to -0.19)	0.53 (-0.03 to 0.84)	0.57 (0.03 to 0.85)	0.60 (0.07 to 0.87)
Emotional exhaustion	-0.45 (-0.80 to 0.14)	-0.72 (-0.91 to -0.28)	-0.86 (-0.96 to -0.59)	-0.55 (-0.85 to 0.00)	0.43 (-0.06 to 0.79)	0.37 (-0.23 to 0.77)	0.48 (-0.10 to 0.82)
Injury	-0.60 (-0.87 to -0.07)	-0.72 (-0.91 to -0.28)	-0.80 (-0.94 to -0.45)	-0.67 (-0.89 to -0.19)	0.53 (-0.03 to 0.84)	0.62 (0.11 to 0.87)	0.65 (0.15 to 0.88)
Being in shape	0.44 (-0.15 to 0.80)	0.52 (-0.04 to 0.83)	0.46 (-0.12 to 0.81)	0.58 (0.04 to 0.86)	-0.36 (-0.76 to 0.24)	-0.63 (-0.88 to -0.12)	-0.55 (-0.85 to 0.00)
Personal accomplishment	0.06 (-0.51 to 0.59)	0.55 (0.00 to 0.85)	0.44 (-0.15 to 0.80)	0.26 (-0.34 to 0.71)	0.09 (-0.49 to 0.61)	-0.42 (-0.79 to 0.17)	-0.26 (-0.71 to 0.34)
Self-efficacy	0.21 (-0.39 to 0.62)	0.51 (-0.06 to 0.83)	0.34 (-0.26 to 0.75)	0.31 (-0.29 to 0.74)	-0.05 (-0.59 to 0.52)	-0.55 (-0.85 to 0.00)	-0.40 (-0.78 to 0.19)
Self-regulation	0.20 (-0.39 to 0.68)	0.69 (0.22 to 0.90)	0.41 (-0.18 to 0.78)	0.25 (-0.35 to 0.70)	0.10 (-0.48 to 0.62)	-0.32 (-0.74 to 0.28)	-0.18 (-0.67 to 0.42)

Associations are expressed as a correlation coefficient with 95 % confidence intervals (parenthesis).

Table 3.5. Association between the profile of mood states (POMS) and the well-being questionnaire (WQ).

	WQ questionnaire						
RESTQ-Sport scales	Motivation	Sleep Quality	Recovery	Appetite	Fatigue	Stress	Muscle soreness
Anger	-0.75 (-0.92 to -0.34)	-0.50 (-0.82 to 0.07)	-0.50 (-0.82 to 0.07)	-0.70 (-0.90 to -0.24)	0.66 (0.17 to 0.89)	0.22 (-0.38 to 0.69)	0.51 (-0.06 to 0.83)
Fatigue	-0.74 (-0.92 to -0.32)	-0.44 (-0.80 to 0.15)	-0.54 (-0.84 to 0.02)	-0.75 (-0.92 to -0.34)	0.62 (0.10 to 0.87)	0.42 (-0.17 to 0.79)	0.49 (-0.08 to 0.82)
Vigour	0.53 (-0.03 to 0.84)	0.59 (0.06 to 0.86)	0.57 (0.03 to 0.85)	0.38 (-0.22 to 0.77)	-0.33 (-0.75 to 0.27)	-0.65 (-0.88 to -0.15)	-0.35 (-0.76 to 0.25)
Depression	-0.73 (-0.91 to -0.30)	-0.62 (0.87 to 0.11)	-0.55 (-0.85 to 0.00)	-0.70 (-0.90 to -0.24)	0.68 (0.21 to 0.90)	0.34 (-0.26 to 0.75)	0.53 (-0.03 to 0.84)
Tension	-0.71 (-0.91 to -0.26)	-0.67 (-0.89 to -0.19)	-0.61 (-0.87 to -0.09)	-0.67 (-0.89 to -0.19)	0.60 (0.07 to 0.87)	0.40 (-0.19 to 0.78)	0.56 (0.01 to 0.85)
Confusion	-0.77 (-0.93 to -0.38)	-0.44 (-0.80 to 0.15)	-0.54 (-0.84 to 0.02)	-0.69 (-0.90 to -0.22)	0.64 (0.14 to 0.88)	0.43 (-0.16 to 0.79)	0.65 (0.15 to 0.88)

Associations are expressed as a correlation coefficient with 95 % confidence intervals (parenthesis).

3.5.4 Discussion

Internal consistency of selected items in the WQ was lower in comparison with the RESTQ-Sport and the POMS scales. These differences may reflect the greater number of questionnaire items in the RESTQ-Sport and POMS scales compared to the single item in each WQ scale. Each scale (e.g. fatigue and recovery) in the RESTQ-Sport and POMS is the summation of several questionnaire items. These questionnaire items could vary, yet still yield the same total score for each scale. In addition, if any of the questionnaire items varied it would have a smaller impact on the total score. Furthermore, the RESTQ-Sport and POMS may only assess subcomponents of each scale and the relative contribution or weighting of each item may differ. Hence, the greater variation observed in WQ items may reflect a global assessment of each item.

Fatigue (α 0.62) and recovery (α 0.65) had the lowest internal consistency in the WQ. The remaining five scales had good internal consistency (> α 0.7). The lower internal consistency may identify a greater sensitivity of these questionnaire items in the WQ. The observed improvements in fatigue and recovery items as the week progressed may reflect participants were subjected to lower training loads than normal. Furthermore, it is difficult control for other life demands which might influence well-being on a daily basis. Hence, such complex interactions may have caused an underestimation of the internal consistency of the questionnaire, particularly for fatigue and recovery, given it is very difficult to replicate the same conditions for each player over the period of a reliability study.

A limitation to the pilot study was 7 out of 13 participants had a one day intermission between the trials resulting in a two day break before filling in the next questionnaires. Filling in the RESTQ-Sport on a more frequent basis than every three days results in an improved internal consistency (α >0.79 vs α >0.59 for 24h and 3 days between testing intervals, respectively; Kellus and Kellmann, 2001). However, in the current study similar levels of internal consistency were evident in comparison with those reported in the RESTQ-Sport filled in 24 h apart (α >0.79; Kellus and Kellmann, 2001).

Weak associations were evident for similar scales and items assessed in the different questionnaires. It should be noted that the confidence intervals for these associations were large highlighting the uncertainty of the relationship. For example, a small negative association to very large positive association between the fatigue scale in the RESTQ-Sport and fatigue item in the WQ was evident. A limitation to the study was the low participant number limits the likelihood of achieving high correlations with smaller confidence intervals. However, given that the scales and items pose different questions, these weak correlations and large confidence intervals are not unsurprising. For example, a weak correlation between the fatigue scale in the RESTQ-Sport and fatigue item in the WQ was evident. The questionnaire items 1) I did not get enough sleep 2) I was tired from work 3) I was dead tired after work 4) I was overtired, in the RESTQ-Sport are not the same as 'how tired / fatigued do you feel today?' in the WQ. The athlete's perception of work may refer to training, college or part-time work. In addition, the player may relate 'how tired / fatigued do you feel today' to items assessed in other scales of the RESTQ-SPORT such as 'physical complaints' and 'lack of energy'. A greater association between the fatigue scale in the POMS and the WQ fatigue item was observed in comparison with the RESTQ-Sport fatigue scale and the WQ fatigue item. This may reflect that the POMS fatigue scale actually directly questions feelings of fatigue in addition to whether participants have been feeling ‘worn out’, ‘listless’, ‘exhausted’, ‘sluggish’, ‘weary’ and ‘bushed’.

The lack of association between scales and items in the RESTQ-Sport and POMS in comparison with the WQ does not render the WQ invalid. Indeed it may highlight its specificity and sensitivity. It is however important to ascertain whether simple questionnaires such as the WQ are sensitive to changes in training load.

3.6 Pilot study 2. Reliability and smallest worthwhile change of selected objective monitoring assessments

3.6.1 Introduction

Several objective assessments have been proposed to monitor training responses in athletes (Al Haddad et al., 2011; Buchheit et al., 2014; Saw et al., 2015). As noted in section 2.6, establishing the TE error and SWC could provide a practical yet scientific approach to identifying meaningful changes when monitoring training responses in individuals.

The day to day reliability (TE) of simple objective monitoring strategies has previously been reported for CMJ height (CV: 4.0 % - 5.6 %; Moir et al., 2004), HR_{rest} (CV~10 %; Al Haddad et al., 2011, Buchheit, 2014), HR_{ex} during and HRR following fixed submaximal exercise bouts (CV: 0.9 % – 25 %; Buchheit, 2014, Lamberts et al., 2004) and for resting time domain measures of HRV (CV: 7 % and 12 %, for lnSDNN and ln rMSSD, respectively; Al Haddad et al., 2011). Monitoring assessments that incorporate measurements with poor reliability will lack the sensitivity to track and identify changes (Hopkins et al., 2000). The ability to track a change is dependent on the magnitude of change that is being assessed. A TE of 7.9 % would be sensitive enough to track a 17 % increase in ln rMSSD following an eight week endurance training programme (Buchheit et al., 2010; Al Haddad et al., 2011). However, in a homogenous group of elite players the SWC is likely to be small, therefore, more reliable measures are needed to detect changes of a smaller magnitude. A lower TE than the SWC indicates good reliability and gives potential to track real changes (Pyne 2003).

Given the plethora of reliability data available on the potential monitoring tools identified, very few studies have considered the SWC (Buchheit, 2014) which if considered with the uncertainty of the measure could be used to identify individual training responses (Hopkins, 2004). The aim of this study was to investigate the reliability and SWC of a range of objective monitoring tools which could be applied to track training responses.

3.6.2 Methods

3.6.2.1 Participants

Thirteen high intensity intermittent team sport players (7 rugby players, 6 football players) volunteered for the study (mean ± SD: age 18 ± 1 yrs, stature 179 ± 6 cm, body mass 81.9 ± 18.6 kg). The participants' normal training involved 3-4 sessions per week plus a competitive match.

3.6.2.2 Study Design

Each participant carried out a battery of objective monitoring assessments on three occasions during a five day period. CMJ (section 3.4.3), HR_{rest} (section 3.4.6), HRV (section 3.4.6), HR_{ex} (section 3.4.7) and HRR (section 3.4.7) were determined using the protocols previously described. Each individual test was carried out at a same time each day to control for diurnal variations (Figure 3.2).

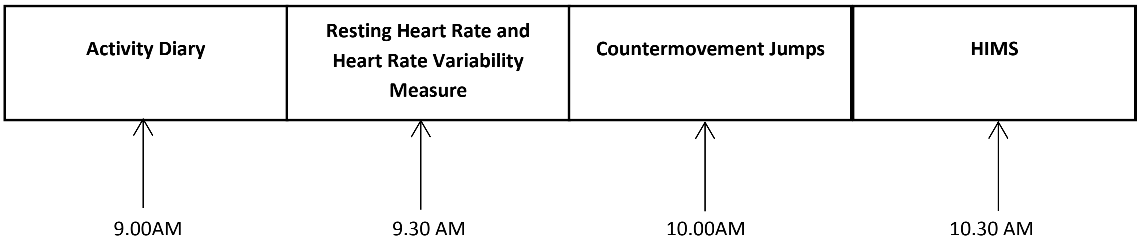


Figure 3.2. Testing schedule for battery of objective monitoring assessments tests.

The study was undertaken in a low load week where no training was undertaken and there was no competitive match. Participants were asked to refrain from carrying out any of their own additional training and to complete an activity diary (Appendix 6) on a daily basis regarding the day prior. Participants did not report any additional training in the activity diary. It was requested that participants wear the same footwear and training kit on each day, carry out their normal breakfast regimen and abstain from caffeine on the morning of the tests.

HR_{rest} and HRV were measured in a relaxed and familiar environment (mean ± SD: Temperature 20.0 ± 1.1 $^{\circ}$C; Humidity 40.0 ± 2.6 %). All subsequent tests including the CMJ and the HIMS were carried out in an indoor sports hall (mean ± SD: Temperature 17.4 ± 0.4 $^{\circ}$C; Humidity 41.7 ± 5.3 %). Prior to the CMJ and submaximal HR test participants were subjected to a standardised warm up. The warm up involved a progressive increase in exercise intensity incorporating sport specific dynamic exercises (e.g. lunges, squats, kick throughs, skips, jumps) and running between two lines 20 m apart.

3.6.2.3 Statistical analysis

The distribution of each variable was examined by a Shapiro-Wilks normality test. Non-normally distributed HRV data was transformed using the natural logarithm to allow statistical parametric comparisons. Mean ± SD were reported for each of the three trials for HRV, HIMS and CMJ variables. 'Within-subject variation' for the three trials, expressed as TE, was calculated for HRV, HIMS and CMJ variables using the SD of the change in mean scores as described by Taylor et al., (2010). TE was reported in absolute units and as a CV %. The SWC was set as 0.25 of the between subject standard deviation of the mean of the 3 trials (Taylor et al., 2010; see section 2.6).

3.6.3 Results

Peak CMJ time and peak CMJ height across the three trials are reported in Table 3.6. The reliability of peak CMJ time (TE: 15 ms, CV: 2.7 %) and CMJ height (TE: 2.0 cm, CV: 5.2 %) are reported in Table 3.7. Peak CMJ time and peak CMJ height yielded slightly higher TE when compared with the SWC.

Table 3.6. Peak countermovement jump (CMJ) time and height following the three trials.

	Trial 1	Trial 2	Trial 3	Mean
Time (ms)	564 ± 44	564 ± 40	547 ± 42	558 ± 42
Height (cm)	38.6 ± 6.4	39.0 ± 5.5	36.9 ± 5.7	38.1 ± 5.9

Mean ± SD for CMJ time (time), CMJ height (height). n=13.

Table 3.7. Measures of reliability for peak countermovement jump (CMJ) time and height from trial to trial.

		Trial 2 – 1	Trial 3 – 2	Mean	SWC
Time	TE (ms)	18 (13-30)	11 (8-18)	15 (12-22)	11
	CV	3.2 (2.3-5.3)	2.0 (1.4-3.2)	2.7 (2.2-3.9)	2.0
Height	TE (cm)	2.4 (1.7-4.0)	1.6 (1.1-2.6)	2.0 (1.6-3.1)	1.5
	CV	6.2 (4.4-10.1)	4.2 (2.9-6.9)	5.2 (4.2-8.1)	3.9

Typical error of measurement [TE (± 95 % confidence limits)], TE expressed as a coefficient of variation [CV, % (± 95 % confidence limits)] for CMJ time (time) and CMJ height (height). The smallest worthwhile change (SWC) derived from 0.25 of the mean between participant SD in table 3.6 is also presented. n=13.

HR_{rest} and HRV across the three trials are reported in Table 3.8. The reliability of HR_{rest} (TE: 4 $b{\cdot}min^{-1}$, CV: 6.0 %) and HRV (TE: 0.09 ms, CV: 4.9 % and 0.13 ms, CV: 8.7 % for ln SDNN and ln rMSSD, respectively) is shown in Table 3.9. The SWC for measures of $HR_{rest,}$ ln SDNN and ln rMSSD was ~50 % lower than the TE.

Table 3.8. Measures of resting heart rate (HR_{rest}) and heart rate variability (HRV) at rest following the three trials.

	Trial 1	Trial 2	Trial 3	Mean
HR_{rest} ($b{\cdot}min^{-1}$)	65 ± 6	68 ± 7	68 ± 7	67 ± 7
ln SDNN (ms)	1.82 ± 0.19	1.84 ± 0.15	1.88 ± 0.17	1.85 ± 0.17
ln rMSSD (ms)	1.73 ± 0.29	1.70 ± 0.30	1.76 ± 0.30	1.73 ± 0.30

Mean ± SD for mean resting heart rate (HR_{rest}), the natural logarithm of: the standard deviation of R-R intervals (ln SDNN) and the root square of the mean squared differences of successive R-R intervals (ln rMSSD). n=13.

Table 3.9. Measures of reliability for resting heart rate (HR_{rest}) and heart rate variability (HRV) indices at rest from trial to trial.

		Trial 2 – 1	Trial 3 – 2	Mean	SWC
HR_{rest}	TE ($b{\cdot}min^{-1}$)	3 (3-6)	4 (3-6)	4 (3-5)	2
	CV	4.5 (4.5-9.0)	5.9 (4.4-8.8)	6.0 (4.5-7.5)	3.0
ln SDNN	TE (ms)	0.09 (0.06-0.14)	0.09 (0.07-0.15)	0.09 (0.07-0.14)	0.04
	CV	4.9 (3.3-7.7)	4.8 (3.8-8.1)	4.9 (3.8-7.6)	2.2
ln rMSSD	TE (ms)	0.13 (0.10-0.22)	0.16 (0.11-0.26)	0.15 (0.11-0.22)	0.08
	CV	7.6 (5.8-12.8)	9.2 (6.4-15.0)	8.7 (6.4-12.7)	4.6

Typical error of measurement [TE (± 95 % confidence limits)], TE expressed as a coefficient of variation [CV, % (± 95 % confidence limits)] for mean resting heart rate (HR_{rest}), the natural logarithm of: the standard deviation of R-R intervals (ln SDNN) the root square of the mean squared differences of successive R-R intervals (ln rMSSD). The smallest worthwhile change (SWC) derived from 0.25 of the mean between participant SD in table 3.8 is also presented. n=13.

HR indices for each stage of the HIMS are presented in Table 3.10. Table 3.11 shows trial to trial reliability improved with increasing exercise intensity and was best for HR_{ex} and HRR recovery during and following (one minute recovery) stage 4 (TE: 3 $b \cdot min^{-1}$, CV: 1.5 % and TE: 8 $b \cdot min^{-1}$, CV: 4.9 % for HR_{ex} and HRR recovery, respectively). The SWC was slightly smaller than the TE for HR_{ex} (1.0 % vs. 1.5 %) and >50 % smaller for HRR (1.8 % vs 4.9 %) in stage 4. When HRR was expressed as a percentage of HR_{ex}, reliability was between 9.9 % - 20.6 % for all exercise stages.

Table 3.10. Measures of heart rate (HR) during the heart rate interval monitoring system (HIMS) for the three trials.

	Trial 1	Trial 2	Trial 3	Mean
HR_{ex} stage 1 ($b \cdot min^{-1}$)	157 ± 10	157 ± 10	150 ± 7	155 ± 10
HRR stage 1 ($b \cdot min^{-1}$)	103 ± 20	103 ± 18	92 ± 14	99 ± 17
% HRR stage 1	34.7 ± 11.2	34.3 ± 9.6	38.7 ± 6.9	35.9 ± 9.4
HR_{ex} stage 2 ($b \cdot min^{-1}$)	173 ± 11	173 ± 10	164 ± 12	170 ± 11
HRR stage 2 ($b \cdot min^{-1}$)	125 ± 13	123 ± 11	107 ± 17	118 ± 14
% HRR stage 2	27.8 ± 7.1	28.6 ± 5.3	34.8 ± 8.7	30.4 ± 7.1
HR_{ex} stage 3 ($b \cdot min^{-1}$)	185 ± 9	185 ± 9	180 ± 10	183 ± 9
HRR stage 3 ($b \cdot min^{-1}$)	147 ± 17	145 ± 14	130 ± 19	141 ±17
% HRR stage 3	20.8 ± 7.8	21.5 ± 6.0	28.1 ± 7.9	23.5 ± 7.3
HR_{ex} stage 4 ($b \cdot min^{-1}$)	195 ± 7	197 ± 8	191 ± 9	194 ± 8
HRR stage 4 ($b \cdot min^{-1}$)	164 ± 12	168 ± 13	158 ± 14	163 ± 13
% HRR stage 4	16.0 ± 5.4	14.5 ± 5.6	17.5 ± 5.9	16.0 ± 5.7
HRR stage 4 (2) ($b \cdot min^{-1}$)	132 ± 15	134 ± 13	123 ± 14	130 ± 14
% HRR stage 4 (2)	31.1 ± 7.6	31.8 ± 6.5	35.8 ± 6.3	33.2 ± 6.8

Mean ± SD for heart rate during each exercise stage calculated as the peak HR during the final 30 seconds of each stage (HR_{ex}), heart rate recovery calculated following a one minute recovery period after each exercise stage (HRR) [(2) denotes a two minute recovery period following the fourth stage] and HRR expressed as a percentage of HR_{ex} (% HRR) [(2) denotes a two minute recovery period following the fourth stage]. n=9.

Table 3.11. Measures of reliability for heart rate (HR) indices during the heart rate interval monitoring system (HIMS) from trial to trial.

		Trial 2 – 1	Trial 3 – 2	Mean	SWC
HR_{ex} stage 1	TE ($b{\cdot}min^{-1}$)	4 (3-7)	4 (3-9)	4 (3-7)	3
	CV	2.5 (1.9-4.5)	2.6 (2.0-5.9)	2.6 (1.9-4.5)	1.9
HRR stage 1	TE ($b{\cdot}min^{-1}$)	13 (9-24)	10 (7-20)	12 (8-20)	4
	CV	12.6 (8.7-23.3)	10.3 (7.2-20.5)	12.1 (8.1-20.2)	4.0
% HRR stage 1	TE (%)	6.8 (4.6-13.0)	5.2 (3.5-9.8)	6.0 (4.4-10.2)	2.4
	CV	19.7 (13.3-37.7)	14.2 (9.6-26.8)	16.7(12.3-28.4)	6.7
HR_{ex} stage 2	TE ($b{\cdot}min^{-1}$)	4 (3-7)	5 (3-10)	4 (3-8)	3
	CV	2.3 (1.7-4.0)	3.0 (1.8-5.9)	2.4 (1.8-4.7)	1.8
HRR stage 2	TE ($b{\cdot}min^{-1}$)	8 (6-16)	12 (8-22)	10 (7-17)	4
	CV	6.5 (4.8-12.9)	10.4 (7.0-19.1)	8.5 (5.9-14.4)	3.4
% HRR stage 2	TE (%)	3.6 (2.4-6.9)	5.4 (3.6-10.3)	4.6 (3.3-7.7)	1.8
	CV	12.8 (8.5-24.5)	17.0 (11.4-32.5)	15.1 (10.9-25.3)	5.9
HR_{ex} stage 3	TE ($b{\cdot}min^{-1}$)	3 (2-5)	4 (3-7)	3 (2-6)	2
	CV	1.6 (1.1-2.7)	2.2 (1.6-3.8)	1.6 (1.1-3.3)	1.1
HRR stage 3	TE ($b{\cdot}min^{-1}$)	8 (5-15)	8 (5-15)	8 (6-13)	4
	CV	5.5 (3.4-10.2)	5.8 (3.6-10.9)	5.7 (4.3-9.2)	2.8
% HRR stage 3	TE (%)	3.3 (2.2-6.2)	3.3 (2.2-6.3)	3.3 (2.4-5.5)	1.8
	CV	15.6 (10.4-29.3)	13.3 (8.9-25.4)	14.0 (10.2-23.4)	7.7
HR_{ex} stage 4	TE ($b{\cdot}min^{-1}$)	3 (2-5)	3 (2-7)	3 (2-5)	2
	CV	1.5 (1.0-2.6)	1.5 (1.0-3.6)	1.5 (1.0-2.6)	1.0
HRR stage 4	TE ($b{\cdot}min^{-1}$)	9 (6-17)	7 (5-14)	8 (6-14)	3
	CV	5.4 (3.6-10.2)	4.3 (3.1-8.6)	4.9 (3.7-8.6)	1.8
% HRR stage 4	TE (%)	4.0 (2.7-7.6)	2.5 (1.7-4.8)	3.3 (2.4-5.6)	1.4
	CV	26.2 (17.7-49.8)	15.6 (10.6-30.0)	20.6 (15.0-35.0)	8.8
HRR stage 4 (2)	TE ($b{\cdot}min^{-1}$)	8 (5-15)	8 (5-16)	8 (6-13)	4
	CV	6.0 (3.8-11.3)	6.2 (3.9-12.5)	6.2 (4.6-10.0)	3.1
% HRR stage 4	TE (%)	3.3 (2.2-6.3)	3.2 (2.2-6.1)	3.3 (2.4-5.5)	1.7
	CV	10.5 (7.0-20.0)	9.5 (6.5-18.0)	9.9 (7.2-16.6)	5.1

Typical error of measurement [TE (± 95 % confidence limits)], TE expressed as a coefficient of variation [CV, % (± 95 % confidence limits)] for heart rate during each exercise stage calculated as the peak HR during the final 30 seconds of each stage (HR_{ex}), heart rate recovery calculated following a one minute recovery period after each exercise stage (HRR)[(2) denotes a two minute recovery period following the fourth stage] and HRR expressed as a percentage of HR_{ex} (% HRR) [(2) denotes a two minute recovery period following the fourth stage]. The smallest worthwhile change (SWC) derived from 0.25 of the mean between participant SD in table 3.10 is also presented. n=9.

3.6.4 Discussion

The key finding of the pilot study was that the selected objective monitoring assessments showed differing levels of reliability. Objective assessments which had a TE close to the SWC were CMJ height and CMJ time and HR_{ex}. Measures of HR_{rest}, HRV and HRR had a higher TE in comparison with the SWC.

The high reliability and SWC observed for CMJ time and height could facilitate the tracking of small performance changes (Pyne et al 2004). However, further research is needed to identify whether CMJ is sensitive to changes in training load. Previously reported reliability measures for peak CMJ height (CV: 2.8 % - 5.6 %; Al Haddad et al., 2015, Moir et al., 2004, Nuzzo et al., 2011) are similar to those reported in the present study (5.2 %). Interestingly, few studies publish flight time from which jump height is calculated. In the present study jump height was less reliable (CV: 5.2 %) in comparison with jump time (CV: 2.7 %). It could be suggested that by reporting jump height some sensitivity of the CMJ is being disregarded. Therefore, to detect meaningful changes the use of CMJ time might be considered, as opposed to other CMJ measures. Conversely, coaches tend to be more familiar and comfortable with CMJ data being reported as jump height.

Measures of HR_{rest} and HRV showed slightly improved trial to trial reliability (CV: 5.0 % vs. 11.1 %, CV: 4.9 vs. 6.9 % and 8.7 vs. 12.3 for HR_{rest}, ln SDNN and ln rMSSD, respectively) in comparison with previous studies (Al-Haddad et al., 2011). The TE of between approximately 5-10 % for resting HR and HRV indices may have the potential to track large changes over the time period of several weeks or months. However, using measures of resting HR and HRV indices to track small meaningful fluctuations on a day to day basis may be limited.

In agreement with previous studies, the reliability of the HIMS improved with increasing exercise intensity (Lambert et al., 2004; Lambert and Lamberts 2009). Hence, the final stage (stage 4) should be used to assess changes in HR_{ex}. The present study observed lower reliability for HR_{ex} (CV: 1.5 vs. 0.9 % - 1.4 %) and HRR (CV: 4.9 vs 1.5 % - 2.9 %) in stage four of the test in comparison with previous studies (Lambert et al., 2004; Lambert and Lamberts 2009). One possible reason for this is the present study measured HR at 10 second intervals whereas the previous studies measured HR at ≤ 5 second intervals, therefore some sensitivity may have been lost. In the present study, the SWC was slightly lower than trial to trial reliability for HR_{ex} (CV: 1.0 % vs. 1.5 %) potentially allowing changes of a small magnitude to be identified. However, poorer reliability for HRR (approximately 2.5 fold greater than the SWC) will reduce sensitivity and only allow changes of a greater magnitude to be detected. Similarly, the large variation (CV: 9.9 % - 20.6 %) for HRR expressed as a percentage of HR_{ex} will make assessing changes of a small magnitude unfeasible.

In conclusion, CMJ and submaximal HR measures with a TE similar to the SWC measures could be useful in monitoring changes of a small magnitude. Measures which have a greater TE in comparison with the SWC may still be of use, however the smallest magnitude of change they can detect will be larger therefore these measures may be less sensitive. The sensitivity of these objective monitoring strategies to changes in training load will be investigated further in chapter four.

3.7 Pilot study 3. Assessing the validity of Heart Rate based training load measures

3.7.1 Introduction

The use of HR based assessments to assess training load is discussed in section 2.5.5. Identifying which method has the strongest dose response relationship with changes in aerobic performance would establish the validity of various HR based measures and highlight the most appropriate HR based measure to use to asses training load in elite youth football players.

The aim of the pilot study was to identify changes in aerobic performance during a pre-season period and assess the criterion validity of various HR based methods based on dose response relationships.

3.7.2 Methods

3.7.2.1 Participants

Eleven full-time U18 academy outfield football players from a club with category two status volunteered and provided informed consent for the study. (Mean ± SD: age 17 ± 1 yrs, stature 178.1 ± 4.5 cm, body mass 70.3 ± 4.9 kg, skinfolds 60.3 ± 16.9 mm).

3.7.2.2 Study design

The study was carried out in a 5 week pre-season period described in chapter five (5.2.3). In brief, pre-season included 17 training sessions, 6 matches and 9 rest days during a 33 day period. Participants performed two incremental exercise tests five weeks apart. S4 was determined as previously described in section 3.4.1. HR based measures of internal load (bTRIMP, Edwards TRIMP, Lucia's TRIMP, team TRIMP, time spent above 85 % of heart rate reserve (HR_{res}) and time spent above HR_{res} at S4 were calculated for each participant in all on-field training sessions.

3.7.2.3 Heart rate based measures of internal load

HR_{rest} was assessed prior to any testing procedures carried out at 8.30 AM on the first day of testing as described in section 3.4.6. Maximum HR was attained during the incremental treadmill test as previously described (section 3.4.1). Mean exercising HR during the final 30 seconds of each stage of exercise was recorded and plotted against blood lactate to generate the TRIMP curves using exponential interpolation where required by HR method. HR was measured in all training sessions and matches throughout the 5 week pre-season period. HR was sampled at 1 s intervals. HR data were downloaded following each training session or match using Polar Team 2 Precision software (Polar, OY, Finland). 13 out of 256 HR files were not available due to issues in data collection. For any missing data points the average for each player on that given day throughout the pre-season period was used in analysis.

3.7.2.4 TRIMP calculations

Banister's TRIMP (Banister, 1991) was calculated using formula 1.

(Formula 1) Duration x ΔHR x $0.64e^{1.92x}$

ΔHR is equal to (HR_{ex} – HR_{Rest}) / (HR_{Rest} – HR_{max}), *e* is equal the base of Naperian's logrithim, *x* equals ΔHR and 1.92 represents a generic constant for males, established by Banister (1991), based on the relationship between HR and blood lactate during incremental exercise. The Edwards TRIMP method (Edwards, 1993) was calculated using five 10 % zone widths of each player's HR_{res} (HR_{ex} – HR_{Rest}). The time spent in each arbitrary zone was multiplied by a coefficient (50-60 % x 1, 60-70 % x 2, 70-80 % x3, 80-90 % x 4, 90-100 % x 5) and summated. Lucia's TRIMP was determined using a three zone method (Lucia et al., 2003). The zones for each player were established using HR at speed at a fixed blood-lactate concentration of 2 $mmol{\cdot}l^{-1}$ (S2) and S4 determined during the incremental treadmill test. Time spent in the zones low (S2), moderate (S2 to S4) and high > S4 were multiplied by coefficients of one, two and three, respectively and summated. Team TRIMP was calculated as described by Akubat et al., (2012) using formula 2 and the exponential formula created from the pooled team data (Figure 3.3).

(Formula 2) Duration x ΔHR x $0.5318e^{2.5804x}$

ΔHR is equal to (HR_{ex} – HR_{Rest}) / (HR_{Rest} – HR_{max}), *e* is equal to the base of Naperian's logrithim, x equals ΔHR and 0.5318 and 2.5804 represent the constants based on the pooled team data (Figure 3.3). iTRIMP was calculated using an exponential formula as described in the Team TRIMP method. However, the constants were derived for each participant based on their individual HR blood lactate relationship. The total time spent above 85 % of HR_{res} and the total time spent above HR_{res} at S4 was summated.

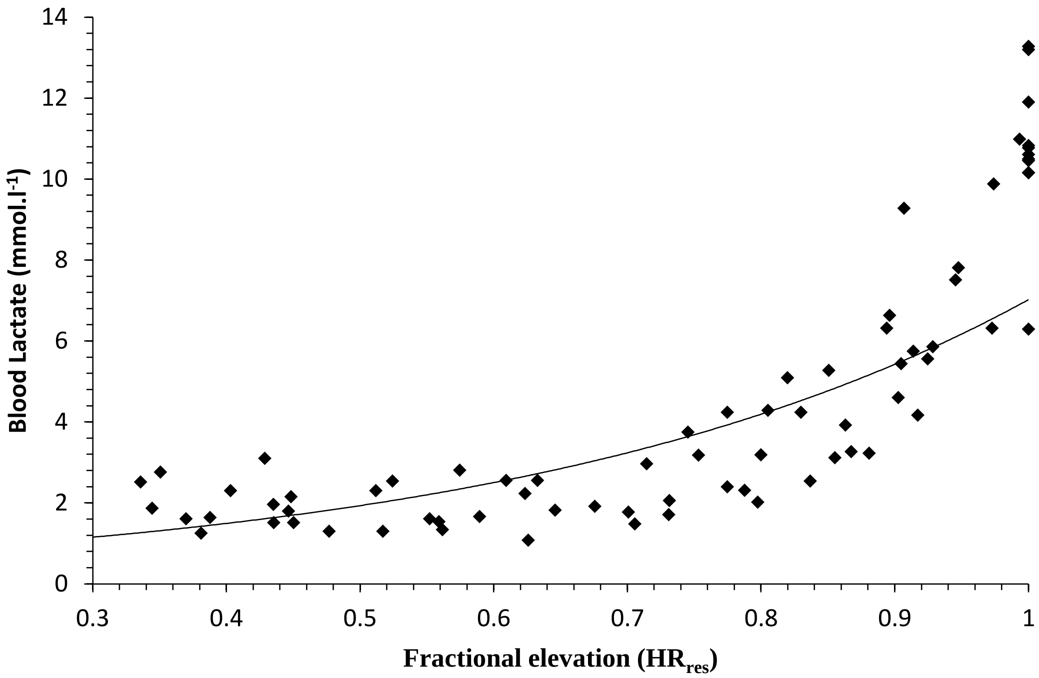


Figure 3.3. Team blood lactate – HR relationship determined in the incremental treadmill test (n=11)

<u>3.7.2.5 Statistical analysis</u>

Relationships between HR based training load methods and changes in aerobic performance (S4) were assessed using Pearson's product moment correlation. Effect sizes were qualitatively described as trivial (<0.09), small (0.10-0.29), moderate (0.30-0.49), large (0.50 to 0.69), very large (0.70 to 0.89), nearly perfect (0.90 to 0.99) and perfect (1.00) (Hopkins et al., 2009). All analysis was carried out using SPSS.

3.7.3 Results

Small to moderate relationships between S4 and various HR based methods were evident (Table 3.12). The iTRIMP method had the strongest linear relationship (Table 3.12).

Table 3.12. Relationships between various HR based methods of quantifying training load and changes in speed at a fixed blood-lactate concentration of 4 $mmol \cdot l^{-1}$ (S4; n=11).

	R	Effect size
Banister TRIMP	0.26 (-0.41 to 0.74)	Small
Edwards TRIMP	0.25 (-0.40 to 0.74)	Small
Lucia TRIMP	0.24 (-0.42 to 0.73)	Small
Team TRIMP	0.34 (-0.33 to 0.78)	Moderate
iTRIMP	0.41 (-0.25 to 0.81)	Moderate
Time spent above 85 % of HR_{res}	0.13 (-0.51 to 0.68)	Small
Time spent above HR_{res} at S4	0.08 (-0.55 to 0.65)	Trivial

95% confidence intervals (parenthesis).

3.7.4 Discussion

The main findings of the pilot study was that the iTRIMP method identified the strongest dose response relationship with changes in performance (S4) in comparison with all other HR based methods. Akubat et al., (2012) reported similar findings to the present study with a stronger relationship between changes in aerobic performance and the iTRIMP compared to bTRIMP, Team TRIMP and also sRPE. Section 2.5.5. identified HR based methods that have previously not been validated based on a dose response relationship (Lucia TRIMP, Edwards TRIMP and time spent above 85 % of HR_{res}). These HR based methods are easier to administer in practical setting and do not require laboratory testing. However, such methods yielded a weaker relationship between changes in aerobic performance compared with iTRIMP. Based on the iTRIMP strongest dose response relationship with changes in aerobic performance the iTRIMP will be used as a measure of internal training load in chapter five. However, it is important note that only 17% of the variance in aerobic performance was explained by iTRIMP. Furthermore, the wide confidence intervals (-0.25 to 0.81) highlight the considerable uncertainty in this relationship.

CHAPTER 4

4.0 The sensitivity of well-being and physical performance assessments to changes in training stress, induced by acute low and high training loads, in team sport players.

Pilot studies one (section 3.5) and two (section 3.6) demonstrated that both subjective and objective monitoring assessments were, albeit to varying extents, reliable on a day-day basis. Identifying if such methods are sensitive to high and low loads would determine their utility in detecting training stress, which could be applied temporally to assess aspects of recovery (well-being and physical performance) in elite youth players. This is addressed in chapter four.

4.1 Introduction

Subjective and objective assessments can be applied temporally to assess aspects of recovery to assist coaches in effective training prescription, thus reducing the risk of NFOR alongside optimising the stimulus to promote training adaptation (section 2.5). Accordingly, methods applied to monitor aspects of recovery, including well-being and physical performance assessments, must be sensitive to changes in training stress induced by different training loads.

Simple self-report well-being questionnaires developed 'in-house' have been proposed as valid measures to assess the recovery of well-being following daily training and competition stress (section 2.5.1). As described in section 3.3.1, a subjective self-report questionnaire (WQ), based on items which were previously identified as being sensitive to varied acute and chronic training loads, was designed at a category two academy. To determine its utility in detecting training stress, an investigation of WQ sensitivity to acute high load compared to low load training is required.

The use of objective assessments to identify the maladaptive response associated with NFOR has received considerable attention (Halson, 2014, Saw et al., 2016). Popular objective methods which are simple, cheap and relatively easy to administer outlined in section 2.5 include CMJ (Halson, 2014), HR_{rest} and HRV (Buchheit, 2014). If these methods were sensitive to acute high training loads they could provide valuable information on the physical recovery of elite youth football players.

An individual approach to assessing training responses is seldom considered in the literature (Hopkins, 2004). Individual characteristics will influence the time course of recovery dependent on numerous factors including initial level of fitness, genetics, recovery and training exposure (section 2.4.4). Hence, the monitoring of elite youth football players must be considered on an individual level.

Assessing whether a change is meaningful based on the 'noise' of the measurement and whether the change is of a large enough magnitude to be worthwhile needs to be addressed to elucidate the sensitivity of objective measures on an individual level. Based on TE or 'noise' in the measurement and the SWC, likely limits and a qualitative descriptor can provide a statistical approach to assessing individual changes (see section 2.6). For subjective assessments these statistical approaches are not feasible due to the data being ordinal. Accordingly, these measures must be analysed using a different approach and a shift in the scale of one may indicate a meaningful change in an individual (Hopkins, 2004).

The aim of this study was to investigate group and individual responses to the WQ and objective monitoring assessments. If these monitoring assessments are sensitive to an acute fixed low load and high load bout of high intensity intermittent exercise it would justify their temporal application to assess aspects of player recovery throughout the season.

4.2 Methods

4.2.1 Participants

Ten college academy team sport players (5 rugby players, 5 football players; mean ± SD: age 18 ± 1 yrs, stature 180 ± 7 cm, body mass 86.6 ± 18.5 kg, estimated $\dot{V}O_2$ max 48 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered and provided informed consent for the study. The participants' normal weekly training involved three to four pitch based sessions (120 min per session), 1-2 gym based sessions (45 min per session) plus an 80 or 90 min competitive match.

4.2.2 Study Design

Using a counterbalanced crossover design, participants were assigned to a low load and a high load trial one week apart. Training load (intensity x volume) was manipulated by the participant performing the LIST (Nicholas et al., 2000) for 15 min (low load) or 90 min (high load). WQ responses were assessed prior to (Day 1, 1.30PM) and ~20 h following (Day 2, 9.00AM) the acute high load and low load trials (Figure

4.1). On the day following each trial (~20 h post) objective assessments were recorded (CMJ, HR_{rest} and HRV, Figure 4.1).

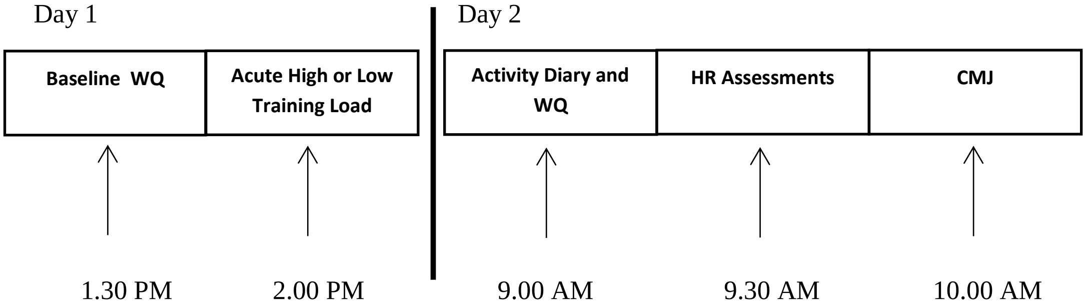


Figure 4.1. Schedule of each trial and time course of objective and subjective assessments.

The WQ (section 3.3.1), CMJ (section 3.4.3), HR_{rest} (section 3.4.6) and resting HRV (section 3.4.6) were carried out as previously described. To ensure consistency, participants were familiarised with all monitoring assessments on a minimum of four occasions prior to undertaking the study. The WQ was completed using a pen and a paper copy of the questionnaire on each occasion. Participants did not discuss questionnaire responses with each other. All participants conducted a standardised 10 min warm up prior to the CMJ. The warm up involved a progressive increase in exercise intensity incorporating sport specific dynamic exercises (e.g. lunges, squats, kick throughs, skips, jumps) and running between two lines 20 m apart. All testing was undertaken in a familiar environment where regular training and testing took place. CMJ were undertaken in an indoor sports hall and all HR recordings were taken in a comfortable recreation room.

The study was conducted during low load training weeks where only one light session with a technical emphasis was completed and there were no competitive matches. In the seven days preceding each trial participants were asked to refrain from carrying out any of their own additional training. In an attempt to quantify any additional training participants were requested to complete an activity diary (Appendix 6) on a daily basis. Seven participants reported carrying out 1-3 additional upper body strength training sessions per week. These were at similar time points prior to the high load and low load trials. No other additional training was reported. Participants were asked to wear the same footwear and training kit on each day, carry out their normal breakfast regime and abstain from caffeine 12 h prior to attending testing sessions.

4.2.3 Loughborough Intermittent Shuttle Test (LIST)

The LIST is a field based simulation designed to replicate the demands of intermittent team sports such as football (Nicholas et al., 2000). Participants were required to run at various speeds (sprinting, running, jogging and walking) determined by the group mean $\dot{V}O_2$ max. The group mean $\dot{V}O_2$ max was estimated using the Yo-Yo IRT1 (Bangsbo et al., 2008) carried out two weeks prior to commencing trials. One block of the LIST was completed (15 min) for the low load trial. Six blocks of the LIST (90 min), with a three minute intermission between each block, were completed for the high load trial. Following each block of the LIST each participant gave an RPE using the CR-10 scale (Impellizzeri et al., 2004). Global training load (AU) was calculated (RPE x duration). The participants carried out one LIST familiarisation (2 x 15 min blocks) two weeks prior to the study. The LIST was carried out in an indoor sports hall.

4.2.4 Statistical analysis

All group analysis was performed using SPSS. For group analysis the data was examined via the Shapiro-Wilks normality test. Paired t-tests were used to determine any differences between the low load and high load trials in normally distributed data. T-Tests with a bootstrapping procedure (used where data are not normally distributed; Kruizenga et al., 2005) of 1000 replications were used to assess any differences in sRPE and the subjective responses in the WQ in the high load and low load trials. Baseline WQ values collected prior to the low load and high load trials were compared. Pre to post delta values from each trial were used to determine differences between WQ responses in the high load and low load trials. Effect sizes were reported using Cohen's *d*, with qualitative description as trivial 0.00 - 0.19, small 0.20 - 0.59, moderate 0.60 - 1.19, large 1.20 – 1.99, very large 2.0 - 4.0 (Hopkins et al., 2009).

To determine individual responses in CMJ and HR indices to the high load and low load trials, the likelihood of a change for each individual was assessed using a specifically designed spreadsheet (Hopkins, 2004). The TE and the SWC, which was established in this population in a prior reliability study (see section 3.6), were used to determine the likelihood of change. In each case the likelihood of change is presented as a percentage probability with a qualitative descriptor; any changes greater than 75 % were considered substantial (Hopkins, 2004, Al Haddad et al., 2015).

4.3 Results

4.3.1 Group responses

Global RPE was greater in the high load compared to low load trials (521 ± 174 vs. 47 ± 33 AU, Table 4.1). Trivial to small differences were observed for items of the WQ between the two baseline measures (*d*=0.1 to 0.5, *P*=0.19 to 0.82*).* Pre to post delta values were lower by a large extent for perceptions of sleep quality and of recovery following the high load compared to low load (-1.0 ± 1.1 AU vs. -0.3 ± 1.1 AU and -2.4 ± 1.8 AU vs. -0.2 ± 1.7 respectively, Table 4.1). Pre to post delta values for perceptions of motivation were moderately lower following the high load compared to low load (-1.9 ± 1.9 AU vs. -0.7 ± 1.7 AU, Table 4.1). Pre to post delta values for perceptions of muscle soreness were moderately higher following the high load compared to low load (2.0 ± 1.7 AU vs. 1.1 ± 1.5 AU, Table 4.1). Pre to post delta values were higher by a small extent for perceptions of appetite, fatigue and stress following the high load compared to low load (Table 4.1).

Table 4.1. Comparison between the effects of high load and low load trials on session rate of perceived exertion (sRPE) during LIST and subsequent well-being questionnaire (WQ) responses.

	Low load	high load	difference	CI	*P* value	Cohens *d*	effect size
Global RPE(AU)	47 ± 33	521 ± 174	474 ± 187	369 to 579	<0.01	3.8	very large
motivation	-0.7 ± 1.7	-1.9 ± 1.9	-1.2 ± 1.8	-2.2 to 0.1	0.12	0.7	Moderate
sleep quality	0.3 ± 1.1	-1.0 ± 1.1	-1.3 ± 1.5	-2.3 to 0.6	0.12	1.2	Large
recovery	-0.2 ± 1.7	-2.4 ± 1.8	-2.2 ± 2.4	-3.6 to -0.7	0.03	1.5	Large
appetite	0.0 ± 1.7	0.7 ± 0.9	0.7 ± 2.1	-0.2 to 2.1	0.38	0.5	Small
fatigue	0.2 ± 1.6	0.9 ± 1.6	0.7 ± 2.3	-0.8 to 1.9	0.41	0.4	Small
stress	0.2 ± 0.2	0.6 ± 1.6	0.3 ± 1.7	-0.7 to 1.4	0.57	0.4	Small
muscle soreness	1.1 ± 1.5	2.0 ± 1.7	0.9 ± 2.8	-0.8 to 2.6	0.36	0.6	Moderate

Mean ± SD, 95 % confidence intervals, p value, t-statistic and effect size for sRPE and pre to post trial delta values in both the high load and low load trials for perceptions of motivation, sleep quality, recovery, appetite, fatigue, stress and muscle soreness. Mean change ± SD reported as a delta value from the high load to low load trial. (n=9).

Trivial differences in peak CMJ height were observed between high load and low load. A very large increase in mean HR_{Rest} was evident following the high load compared to following low load (6 ± 4 b·min^{-1}, Table 4.2). Moderate decreases in indices of HRV were observed following the high load compared to low load (-0.08 ± 0.08 ms, and -0.13 ± 0.08 ms, for ln SDNN and ln rMSSD respectively, Table 4.2).

Table 4.2. Peak countermovement jump (CMJ) performance and indices of heart rate (HR) at rest following the high load and low load trials.

	Peak CMJ height (cm)	Mean HR_{Rest} (b·min^{-1})	ln SDNN (ms)	ln rMSSD (ms)
Low load	37.2 ± 4.4	58 ± 1	1.96 ± 0.09	1.94 ± 0.18
High load	37.2 ± 4.4	64 ± 4	1.88 ± 0.13	1.81 ± 0.18
Mean Change	0 ± 1.8	6 ± 4	-0.08 ± 0.08	-0.13 ± 0.08
CI	-1.3 to 1.3	1 to 10	-0.18 to -0.01	-0.21 to -0.04
T Statistic	-0.04	3.28	-2.64	-3.70
P Value	0.97	0.02	0.04	0.01
Cohens d	0.0	2.1	0.7	0.7
Effect Size	Trivial	very large	Moderate	Moderate

Mean ± SD, 95 % confidence intervals, p value, t-statistic and effect size for countermovement jump (CMJ; n=10) mean resting heart rate (HR_{rest}; n=6), the natural logarithm of: the standard deviation of R-R intervals (ln SDNN; n=6) and the root square of the mean squared differences of successive R-R intervals (ln rMSSD; n=6).

4.3.2 Individual responses

Training load, as indicated by sRPE, ranged from 15 to 105 AU in low load compared to 240 to 810 AU in high load (Table 4.3).

Table 4.3. Estimated $\dot{V}O_2$ max values and session Rate of perceived exertion (RPE) during Loughborough Intermittent Shuttle Test (LIST) in high load and low load trials for individual participants.

Participant	Estimated $\dot{V}O_2$ max (ml·kg^{-1}·min^{-1})	Global RPE (AU)	
		Low load trial	High load trial
A	52	60	420
B	-	75	405
C	50	15	525
D	48	75	240
E	49	15	750
F	51	15	585
G	39	60	810
H	47	30	600
I	51	15	375
J	45	105	495

Data expressed as absolute individual scores for $\dot{V}O_2$ max and sRPE (n=10).

The majority of participants showed poorer perceptions of well-being following the high load compared to low load trials; with 7/9, 7/9, 6/9, 6/9, 5/9, 3/9 and 1/9 participants showing poorer perceptions from pre to post delta values for recovery, sleep quality, motivation, muscle soreness, fatigue, stress and appetite (Table 4.4). Only participant I reported WQ items that did not generally deteriorate following high load compared to low load. This participant had one of the highest $\dot{V}O_2$ max values (Table 4.3).

Table 4.4. Individual differences in well-being questionnaire (WQ) responses between the high load and low load trials.

Participant	Motivation	sleep	recovery	appetite	Fatigue	stress	muscle
A	-2	-1	-3	0	0	0	-1
B	2	-1	-1	-1	-4	0	-4
C	-2	-1	0	0	3	4	1
D	-3	-2	-4	0	2	0	-1
E	-3	-5	-6	1	4	1	6
F	-2	-1	-1	0	1	0	2
G	1	0	-3	6	0	-1	1
H	-2	-1	-4	0	1	1	3
I	0	0	2	0	-1	-2	1

Perceptions of motivation, sleep quality, recovery, appetite, fatigue, stress and muscle soreness calculated as a pre to post trial delta value in both the high load and low load trials. Data presented as a change score between these high load and low load trial delta values. (n=9).

No participant had a substantial chance that the high load had a negative effect on CMJ performance when compared to the effect of the low load (5-72 %, Table 4.5).

Table 4.5. Individual responses following high load and low load trials for peak jump height measured during a countermovement jump (CMJ).

Participant	Low load (cm)	High load (cm)	Change (cm)	Likelihood of effect (%)			Qualitative descriptor
				-ve	Trivial	+ve	
A	40.3	38.6	-1.7	53	34	13	possibly, may not be lower
B	36.0	32.8	-3.2	72	22	5	possibly, may not be lower
C	32.3	33.4	1.1	18	37	44	unlikely, probably not lower
D	37.2	39.0	1.8	13	33	54	unlikely, probably not lower
E	44.7	43.9	-0.8	40	38	21	possibly, may not be lower
F	41.5	41.0	-0.5	36	39	24	possibly, may not be lower
G	30.5	31.0	0.5	24	39	26	unlikely, probably not lower
H	33.2	32.5	-0.7	39	39	22	possibly, may not be lower
I	39.0	39.1	0.1	29	40	31	possibly, may not be lower
J	37.1	40.3	3.2	5	22	72	unlikely, probably not lower

Data presented as absolute scores, delta values, percentage of likelihood of change and qualitative descriptor (n=10). Smallest worthwhile change (SWC) and Typical Error (TE) from reliability data (section 3.6) used to determine likely limits. SWC = 1.5 cm and TE 2.0 cm.

Four individual participants (A, B, F, G) had a substantially higher mean HR_{Rest} following the high load compared to low load (76 % to 91 %, Table 4.6).

Table 4.6. Individual responses following high load and low load trials for mean resting heart rate (HR_{rest}).

Participant	Low load ($b{\cdot}min^{-1}$)	High load ($b{\cdot}min^{-1}$)	Change ($b{\cdot}min^{-1}$)	Likelihood of effect (%)			Qualitative descriptor
				-ve	Trivial	+ve	
A	59	69	10	91	6	2	likely, probably higher
B	57	66	9	89	8	3	likely, probably higher
C	59	60	1	43	27	30	possibly, may not be higher
F	57	65	8	85	10	4	likely, probably higher
G	56	62	6	76	16	9	likely, probably higher
I	59	59	0	36	27	36	possibly, may not be higher

Data presented as absolute scores, delta values, percentage of likelihood of change and qualitative descriptor (n=6). Smallest worthwhile change (SWC) and Typical Error (TE) from reliability data (section 3.6) used to determine likely limits. SWC = 2 $b{\cdot}min^{-1}$ and TE = 4 $b{\cdot}min^{-1}$.

Participants A and B yielded a substantially lower ln SDNN following the high load compared to low load (80 % and 91 %, respectively Table 4.7). In addition, participant

B showed a substantially lower ln rMSSD in high load compared to low load (82 %, Table 4.8). All other participants showed no substantial likelihood of change in HR indices (Table 4.6, Table 4.7 and Table 4.8).

Table 4.7. Individual responses following high load and low load trials for the natural logarithm of the standard deviation of R-R intervals (ln SDNN).

Participant	Low load (ms)	High load (ms)	Change (ms)	Likelihood of effect (%)			Qualitative descriptor
				-ve	trivial	+ve	
A	1.88	1.66	-0.22	91	6	3	likely, probably lower
B	2.00	1.85	-0.15	80	12	7	likely, probably lower
C	1.91	1.89	-0.02	44	24	32	possibly, may not be lower
F	1.88	1.84	-0.04	50	23	27	possibly, may not be lower
G	2.02	1.99	-0.03	47	24	29	possibly, may not be lower
I	2.09	2.03	-0.06	56	22	22	possibly, may not be lower

Data presented as absolute scores, delta values, percentage of likelihood of change and qualitative descriptor (n=6). Smallest worthwhile change (SWC) and Typical Error (TE) from reliability data (section 3.6) used to determine likely limits. SWC = 0.04 ms and TE = 0.09 ms.

Table 4.8. Individual responses following high load and low load trials for the natural logarithm of the root square of the mean squared differences of successive R-R intervals (ln rMSSD).

Participant	Low load (ms)	High load (ms)	Change (ms)	Likelihood of effect (%)			Qualitative descriptor
				-ve	trivial	+ve	
A	1.66	1.51	-0.15	63	23	14	possibly, may not be lower
B	2.09	1.81	-0.28	82	13	5	likely, probably lower
C	2.01	1.96	-0.05	44	28	27	possibly, may not be lower
F	1.79	1.73	-0.06	46	28	26	possibly, may not be lower
G	2.09	1.97	-0.12	57	25	18	possibly, may not be lower
I	2.01	1.91	-0.10	54	26	20	possibly, may not be lower

Data presented as absolute scores, delta values, percentage of likelihood of change and qualitative descriptor (n=6). Smallest worthwhile change (SWC) and Typical Error (TE) from reliability data (section 3.6) used to determine likely limits. SWC = 0.08 ms and TE = 0.15 ms.

4.4 Discussion

The main finding of the study was group responses showed selected items of the WQ (motivation, recovery, sleep quality and muscle soreness), HR_{rest} and indices of HRV were sensitive to changes in acute training load. However, CMJ was not sensitive to acute fluctuations in training load. Individual WQ responses revealed 7/9, 7/9, 6/9, 6/9, 5/9, 3/9 and 1/9 participants reported deteriorations in perceptions of recovery, sleep quality, motivation, muscle soreness, fatigue, stress and appetite, respectively following high load compared to low load. 4/6, 2/6 and 1/6 individuals for HR_{rest}, ln SDNN and ln rMSSD, respectively, reported a substantial chance of a negative response after high load compared to low load.

This study indicates that selected WQ items designed by the sport science practitioners at the club could provide important information on the recovery of well-being following a training stress given their sensitivity to controlled changes in training load. Moderate to large deteriorations in perceptions of motivation, recovery, sleep quality and muscle soreness were evident following the high load compared to low load. These findings are similar to previous studies which reported a reduction in sleep quality and increase in muscle soreness, assessed using a questionnaire developed 'in-house', in elite senior football players following exposure to high training and competition loads (Thorpe et al., 2016).

The WQ items fatigue, stress and appetite only deteriorated to a small extent in the high load trial compared to the low load trial. In contrast, Gastin et al., (2013) reported fatigue and stress, assessed using a questionnaire developed 'in-house', were sensitive to acute high competition loads in senior Australian Rules football players. These differences could be explained by differences in the competitive and non-competitive environment such as the greater psychological stresses associated with competition (Noblet et al., 2003). For example, fatigue and stress could be associated with the mental aspects of competition. Furthermore, participants in the present study might have associated ‘stress’ and ‘fatigue’ with non-training stress and fatigue. The lower sensitivity of these questionnaire items to high load and low load does not render these questionnaire items invalid as they may be sensitive to other stresses elite youth football players are exposed to (Faude et al., 2011; e.g. social, lifestyle and environmental factors). However, these findings highlight the need for the sport science practitioner to understand how each of their players perceives each questionnaire item.

It should be noted that the moderate to large deterioration in perceptions of motivation, sleep quality and muscle soreness had confidence intervals which overlapped zero. Hence, the uncertainty in changes in the WQ responses following high and low training loads should be acknowledged. A limitation to the present study was the low participant number. This may have influenced the width of the confidence intervals. In addition, the width of the confidence intervals are also likely to reflect the individual responses to a fixed training load which are influenced by several factors including maturity (Buchheit and Mendez-Villanueva, 2013) training history, level of fitness and genetics (Faude et al. 2014).

A limitation to the present study was the training load in the LIST was not relative to each individual’s level of fitness. However, differing responses to a fixed load highlights the individual characteristics which sport science practitioners and coaches must account for. Participant I had the lowest RPE load and one of the highest estimated $\dot{V}O_2$ max values. Therefore, the relatively lower internal load could in part explain the lack of any changes in perceptions of well-being in the WQ for participant I. These findings exemplify the need to monitor team based training on an individual level to account for idiosyncratic factors (see section 2.4.6). Furthermore, these findings highlight the potential use of the WQ to identify the recovery of well-being following a training stress, which could be subsequently used to individualise training prescription.

In contrast with participant I, participants A and F reported poorer perceptions of well-being despite high estimated $\dot{V}O_2$ max values. This highlights potentially confounding factors in addition to training load which could influence perceptions of well-being such as relationships and lifestyle (Meeusen et al., 2013). The sensitivity of the WQ to such factors is not necessarily a limitation. If the sport science practitioner has developed a good relationship with the athlete they will be able to discuss the issue and dichotomise whether a reduction in well-being is a result of training stress or other life factors (Saw et al., 2015a).

Providing effective manageable feedback on the individual athlete is important to allow coaches to make informed decisions. A unique aspect of the WQ is the positive and negative scale in which the 'normal' athlete response is anchored to zero. Previously validated questionnaire scales (Gastin et al., 2013, Thorpe et al., 2015) which do not ask players to respond based on their 'normal' response require the collation of data over an extended period to set a baseline (Saw et al., 2016). This gives the WQ greater utility in situations where retrospective data is not available.

Subjective measures have been reported to show greater sensitivity to increased short term and chronic training loads in comparison with objective measures (Saw et al., 2016). The present study reported that group CMJ performance was not sensitive to changes in acute training load. However, HR_{rest} and HRV were sensitive to changes in acute training loads.

CMJ is a simple assessment which could be used as an objective measure of neuromuscular performance prior to training whilst players carry out strength and conditioning work (Twist and Highton, 2013). However, the present study suggests that the CMJ measure using a contact mat is not sensitive to high training loads. In contrast, previous studies show decrements in CMJ performance 24 h and 48 h following a competitive fixture (Ascensao et al., 2011, Fatouros et al., 2010, Magalhaes et al., 2010) and a 90 min match simulation (LIST; Bailey et al., 2007, Magalhaes et al., 2010). These differences could reflect difference in the magnitude of the acute load (De Hoyo et al., 2016, Magalhaes et al., 2010). Furthermore, more expensive equipment such as force plates may be required to detect neuromuscular fatigue in a CMJ (Gathercole et al., 2015).

Group analysis of HR indices in the present study suggests HR_{rest} and HRV measures were sensitive to changes in acute training load. These measures of the autonomic nervous system have previously been proposed as a marker of NFOR and are reported to be sensitive to acute changes in training load (Bosquet et al., 2008, Buchheit, 2014). Therefore, HR_{rest} and HRV may be a useful tool for coaches and practitioners to assess the physical recovery of players.

In an applied setting, monitoring must be carried out on an individual level due to the aforementioned individual differences. On an individual level it has been proposed that HR indices are too variable to assess athletes based upon a single measure (Buchheit, 2014, Plews et al., 2013). Individual increases in 4/6 participants were evident for HR_{rest}, but only 2/6 and 1/6 participants reported a reduction in ln SDNN and ln rMSSD, respectively. Given the magnitude of the 'noise' and the SWC in measures of HR, single infrequent assessments of HR indices may only be sensitive to very large fluctuations in training load. Therefore, frequent daily assessment of HR indices using a rolling average would be required to reduce the 'noise' of the measurement (Buchheit, 2014, Plews et al., 2013).

Practically, HR_{rest} and HRV assessments are not as easy to implement in elite youth team players as originally thought. Collecting HR measures on a daily basis in elite youth football players is not feasible. It is a time consuming process and it is difficult to get the data turned round in a time period which could influence the daily management of players. Furthermore, players lack concentration and get easily bored and often do not carry out the assessments in line with the protocols designed to ensure the validity of the data collected.

A limitation to present study was the participants used in the present study were not elite youth football players. However, they were age matched and were playing team sports to a good level at a college academy. Carrying out such reliability and validation studies in elite youth football players is not practical due to their training schedules.

In conclusion, it seems that daily subjective assessments may provide greater utility in an applied setting in comparison with objective assessments. The WQ designed by the sport science practitioners at the club detected changes in high load and low load, indicating sensitivity to training stress. Hence, the temporal application of the WQ could be used to assess aspects of recovery in elite youth football players.

CHAPTER 5

5.0 Evaluation of well-being and physical performance in elite English youth football players during a 5 week pre-season training period

Chapter four identified that WQ items were sensitive to acute high loads and may be used to assess aspects of recovery of youth team sport players. Chapter five considers the temporal application of these assessments, in addition to physical performance measures, to assess the responses to a low volume high intensity training period (pre-season) aimed at improving physical characteristics in elite youth football players. In addition, pilot study three (section 3.7) identified that the iTRIMP was the HR based training load measure with the strongest dose response relationship with changes in aerobic performance. Therefore, the iTRIMP will be used in chapter five to quantify internal training load.

5.1 Introduction

During the pre-season period there is a need for coaches and sport science practitioners to focus on re-establishing player fitness following the off-season intermission (Silva et al., 2016). Although improvement of physical characteristics is considered the priority above all other performance and development components during pre-season (Jeong et al., 2011), no specific guidelines are given in the EPPP with regard to pre-season training (The Premier League, 2011). To focus on physical performance during this period coaches and sport science practitioners reduce the training volume and concentrate on high intensity, low volume training with adequate recovery between sessions (Verheijen, 2014). The duration of training conducted is therefore likely to be lower than the 12-14 h training per week that, by omission of alternative guidance in pre-season, is inferred by the EPPP.

As highlighted in section 2.4.1. a period of intensified training in pre-season can result in acute physical fatigue which is considered a necessary process to improve physical fitness (Meeusen et al., 2013). However, a lack of adequate recovery prior to the next training session may result in NFOR and / or a reduction in well-being (Meeusen et al., 2013); whereas adequate recovery is more likely to lead to subsequent positive training adaptations in physical characteristics synonymous with high level football performance (Silva et al., 2015). Data from chapter four of this thesis demonstrated that the WQ was sensitive to acute high and low loads and therefore could potentially be applied to assess the recovery of well-being following a training stress. Establishing an optimal training dose which allows for adequate recovery and improves physical performance is an important consideration (Issurin, 2010). Hence, well-being could indicate whether the internal training stimulus is excessive. Yet, well-being must be considered along with assessments indicative of changes in physical performance to identify the changes in fitness over a longer period of training.

Although WQ responses alone could provide valuable information with regard to an aspect of player recovery, physical performance tests may be indicative physical recovery and changes in fitness. The time constraints, logistics, resources and the fatiguing nature of some physical performance assessments preclude these tests from being used to assess physical recovery, which requires regular assessment on an acute basis. However, physical performance tests (e.g. aerobic fitness, sprints) may provide valuable information with regard to the adaptation in short term training meso-cycles (~5 to 8 weeks). In addition, submaximal physical performance assessments which measure HR_{ex} (Buchheit, 2014) and HRR (Aubry et al., 2015, Daanen et al., 2012) may be applied on a weekly basis to assess changes in fitness and fatigue. Therefore it is proposed a combination of assessment methods (WQ and physical performance tests) are required to evaluate responses to internal training loads during the pre-season period.

The team dynamic of football ensures pre-season training is planned on a group basis (Reilly, 2005). If players were exposed to the same external load during pre-season training, the training response will be influenced by several individual characteristics such as maturity (Buchheit and Mendez-Villanueva, 2013), training history (e.g. engagement with off-season programme), genetics and level of fitness (Faude et al., 2014). However, players are not exposed to the same external load in some training modalities such as SSG due to differences in position and style of play (Hill-Haas et al., 2011). Therefore, both individual factors and external factors will influence the internal training load and subsequent response (Impellizzeri et al., 2005). This highlights the need for coaches and sport science practitioners working in elite youth football to consider training responses on both a group and individual level.

The aim of this study was to examine group and individual well-being and physical performance responses during a pre-season period in elite English youth football players.

5.2 Methods

5.2.1 Participants

Eleven full-time U18 academy outfield football players from a club with category two status volunteered and provided informed consent for the study (mean ± SD: age 17 ± 1 yrs; stature 178 ± 5 cm; body mass 70.3 ± 4.5 kg; sum of eight skinfolds 60.4 ± 16.1 mm, at pre-season).

5.2.2 Exclusion criteria

Players injured or unable to take part in testing procedures were removed from the study. Six players were excluded based on this criteria (originally n=17).

5.2.3 Study design

Anthropometrics and physical performance tests were carried out over a two day period prior to (day 1 and day 2) and following (day 36 and day 37) a five week (33 day) pre-season training block. Analysis was split into five weeks (days 1-7 week 1, days 8-14 week 2, days 15-21 week 3, days 22-28 week 4 and days 29-35 week 5). Submaximal physical performance assessments were performed on a weekly basis throughout the pre-season period (day 8, day 15, day 22 and day 29) using the HIMS (section 3.4.7). WQ responses were assessed prior to each training session (3 to 4 occasions per week; section 3.3.1) and the internal training load for each individual was quantified for on-field training sessions and matches using the iTRIMP method (section 3.7.2.4). The temporal application of assessments is shown in Table 5.1. All players had several years of experience performing all assessments and were, therefore, familiarised with the procedures. Of a total of 18 training sessions and six friendly matches, only two participants missed any sessions [Six training sessions and one match (contact injury) and one training session (other engagement) were missed, respectively].

Table 5.1. Time course of monitoring assessments throughout the pre-season training period.

Pre / post training assessments	Weekly assessments	Training day assessments
Body mass (Kg)	HR_{ex}	iTRIMP
Sum of 8 Skinfolds (mm)	HRR	WQ
$\dot{V}O_2$ peak ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)		
S4 ($km{\cdot}hr^{-1}$)		
MAS		
30 m sprint (s)		
CMJ (cm)		
AAT (s)		

Peak oxygen uptake ($\dot{V}O_2$ peak), speed at a fixed blood-lactate concentration of 4 $mmol{\cdot}l^{-1}$ (S4), maximal aerobic speed (MAS), countermovement jump (CMJ), arrowhead agility test (AAT), exercising HR (HR_{ex}) during the final 30 seconds of stage four of the Heart Rate Interval Monitoring System (HIMS), Heart rate recovery (HRR) during the 60 seconds recovery period following stage four of the Heart Rate Interval Monitoring System (HIMS) and well-being questionnaire (WQ).

Anthropometrics were assessed prior to (Day 1) and following (Day 36) pre-season training using the protocols described in section 3.2. The players were split into two groups. Group one completed the incremental treadmill test (section 3.4.1) on day 1 and all other field based physical performance tests [30 m sprint (section 3.4.2), CMJ (section 3.4.3) and AAT (section 3.4.4)] on day 2 using the protocols previously described. Group 2 completed the incremental treadmill test on day two and all other field based physical performance tests day one. Players completed all the pre and post training physical performance tests in the same order and at the same time of day. $\dot{V}O_2$ peak, MAS and S4 were determined as described in section 3.4.1.

All field based physical performance tests and HIMS assessments were carried out on an indoor 3rd generation artificial surface. Players wore football boots during all tests except for CMJ where trainers were worn. Prior to all field based physical performance test procedures players carried out a standardised 10 min warm-up consisting of jogging, running, sprinting and dynamic stretching. The order of the tests was identical on all four testing occasions: 1) CMJ; 2) 30 m Sprint; 3) AAT. A HR monitor (Polar Team 2, OY, Finland) was worn across the chest and recorded HR at 1 s intervals during the HIMS. Seven players did not undertake the HIMS on one occasion each (1 participant on day 8 and 6 participants on day 29). One occasion was due to a player not training on that day due to injury and six were a result of players training at another venue.

The WQ described in Section 3.3.1 was completed prior to training at 9am using a dry wipe marker pen on an A4 laminated white board located above their changing area. Players failed to fill in the WQ on 18 occasions out of 187 (4 in days 8-14, 1 in days 15-21, 1 in days 22-28 and 12 in days 29-35). These were due to players training at a different venue.

A HR monitor (Polar Team 2, OY, Finland) was worn across the chest and recorded HR at 1 s intervals during each on-field training session. An error in iTRIMP data collection occurred in 14 out of 249 sessions with 6 players missing data on 1-4 occasions. The average for training and matches on that given day in other weeks was used for any missing data.

5.2.4 Training

Training intensity was progressed through the pre-season period. The frequency of the training modalities carried out in pre-season training are presented in Table 5.2. Training time consisted of 38 % technical and tactical, 14 % tactical metabolic conditioning, 3 % high intensity interval training, 5 % interval training, 5 % prehab, 12 % strength and conditioning, 2 % multi-directional speed and agility, 2 % speed, 1 % power and 18 % recovery. On-field sessions accounted for 65 % of the total training time (excluding recovery, strength and conditioning and prehab).

Table 5.2. Frequency of training modalities carried out during pre-season training.

Training modality	Week 1	Week 2	Week 3	Week 4	Week 5
Games	-	1	1	2	2
Testing	2	-	-	-	-
Technical / Tactical	3	3	6	6	7
TMC	2	2	4	1	-
HIIT	-	-	1	1	-
Interval training	1	2	-	-	-
Prehab	1	2	2	1	1
S & C	1	1	2	-	-
WU MDS / Agility	-	2	1	-	-
WU Speed	-	-	-	1	1
WU Power	-	-	-	-	1
Recovery	2	2	1	1	-

Tactical metabolic conditioning (TMC), High intensity interval training (HIIT), Strength and conditioning (S & C), Warm up – Multi-directional speed / Agility focus (WU MDS / Agility), Warm up – Speed focus (WU Speed) and warm up power focus (WU Power). Note that technical and tactical refers to one practice (15-40 mins) within a training session.

5.2.5 Statistical analysis

All group analysis was performed using SPSS. A Shapiro-Wilk test was used to determine whether the data was normally distributed.

Paired T-Tests were used to identify any changes in anthropometrics and physical performance tests post training compared to pre-training. Results are reported as mean ± SD and 95 % CI. Significance for all analysis was set at $P<0.05$. Effect sizes were categorised using Cohen's *d* as trivial (<0.19), small (0.20-0.59), moderate (0.60-1.19) and large (1.20-1.99) and very large (2.0-4.0) (Hopkins et al., 2009).

The group mean ± SD and 95 % CI of the individual's absolute weekly mean WQ responses were calculated and were not typically normally distributed. General linear model analysis of variance (GLM ANOVA) with a bootstrapping procedure of 1000 replications was used to identify any differences in well-being across training weeks. Confidence intervals were set at 95 % (95 % CI) and were calculated using Tukey pairwise comparisons. The 95 % CI of differences between means that failed to overlap zero were considered statistically significant. Significance for all analysis was set at $P<0.05$.

GLM ANOVA with repeated measures was used to assess for changes in internal training and HIMS between training weeks. If Mauchley's test of sphericity was violated the degrees of freedom were adjusted using the Greenhouse-Geiser correction (Field, 2005). Where differences were evident post-hoc pairwise comparisons (Bonferonni adjusted) were used to identify where the differences occurred. Results are reported as mean ± SD and 95 % CI. Effect sizes for all GLM ANOVA were categorised using partial eta squared (η_p^2) as trivial (<0.09), small (0.10-0.29), moderate (0.30-0.49) and large (>0.50) (Hopkins et al., 2009).

Pearson's Product Moment Correlation was used to assess any relationships between internal training load and both WQ responses and changes in aerobic performance. One day, cumulative two day, cumulative three day, cumulative seven day and total cumulative internal training load were compared with next day WQ responses. Effect sizes for correlations were calculated as trivial (<0.09), small (0.10-0.29), moderate

(0.30-0.49), large (>0.50-0.69), very large (0.70-0.89), nearly perfect (0.90-0.99) and perfect (1.00) (Hopkins et al., 2009).

To determine individual changes in physical performance tests, pre-post training and weekly changes in HIMS assessments, the likelihood of a change was calculated and presented as previously described in section 4.2.4. The TE and SWC for HIMS assessments was derived from the pilot study in section 3.6 (Table 3.11). Difficulties in assessing TE in an applied setting for physical performance tests was discussed in section 2.6. In a practical setting some attempt must be made to acknowledge the uncertainty of the measure when assessing individual changes. Therefore the TE previously determined in similar athletic populations was used. The SWC was established for all physical performance tests was based on 0.25 of the between participant SD of pre training values in table 5.5 (Taylor et al., 2010). The TE and SWC used to assess individual changes are outlined in Table 5.3.

Table 5.3. The typical error (TE) and smallest worthwhile change (SWC) used determine to the likelihood of change in individual participants.

	TE (% coefficient of variation)	SWC (absolute units)	Source to determine TE
$\dot{V}O_2$ peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	4.8	1 ($ml \cdot kg^{-1} \cdot min^{-1}$)	Weltman et al., 1990
MAS ($km \cdot hr^{-1}$)	1.4	0.3 ($km \cdot hr^{-1}$)	Weltman et al., 1990
S4 ($km \cdot hr^{-1}$)	2.4	0.3 ($km \cdot hr^{-1}$)	Prettin et al., 2013
30 m sprint (s)	0.8	0.04 (s)	D'Auria et al., 2006
CMJ (cm)	3.2	1.5 (cm)	Harsley et al., 2010
AAT (s)	0.9	0.07 (s)	Harsley et al., 2010
HR_{ex}	1.5	2 ($b \cdot min^{-1}$)	Section 3.6
HRR	4.9	3 ($b \cdot min^{-1}$)	Section 3.6

Peak oxygen uptake ($\dot{V}O_2$ peak), maximal aerobic speed (MAS), speed at blood-lactate concentration of 4 $mmol \cdot l^{-1}$ (S4), 30 m sprint tests, the arrowhead agility test (AAT), countermovement jump (CMJ), heart rate recovery (HRR) during the 60 seconds recovery period following stage four of the Heart Rate Interval Monitoring System (HIMS) and exercising heart rate (HR_{ex}) during the 60 seconds recovery period following stage four of the Heart Rate Interval Monitoring System (HIMS).

5.3 Results

5.3.1 Training load

Data collated from 249 individual on-field training sessions and matches revealed mean weekly squad training and match duration was 7.2 ± 1.7 h and an average weekly iTRIMP of 838 ± 246 AU. The daily distribution of internal load training and match load across each week is presented in Figure 5.1.

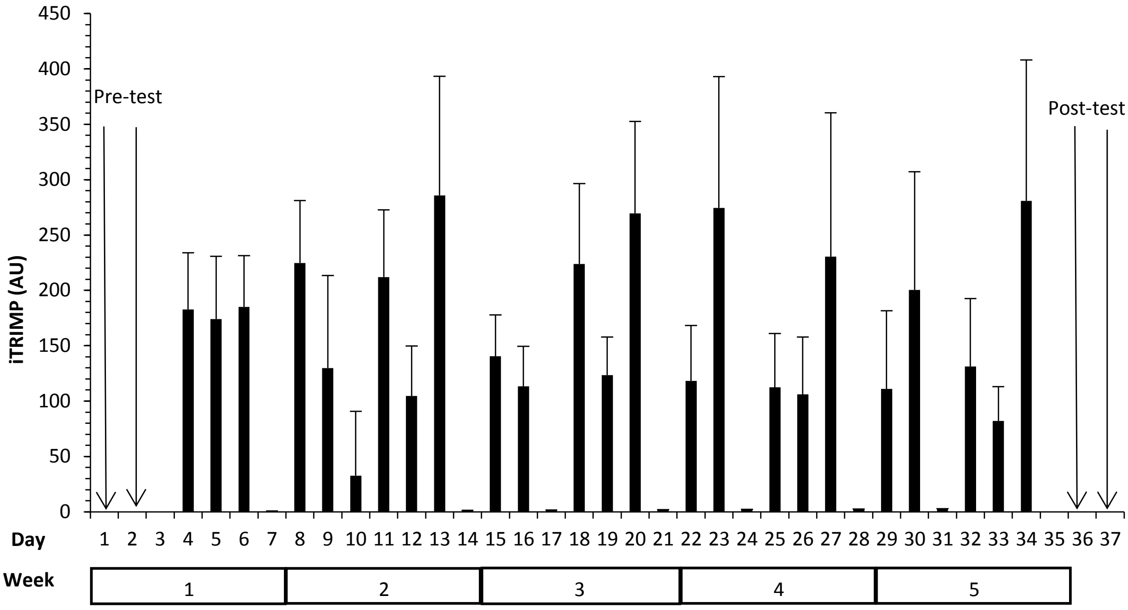


Figure 5.1. Daily distribution of training load throughout a five week pre-season training period in elite category two English academy football players. Mean ± SD.

Training load increased to a large extent from week 1 (Figure 5.2). Pairwise comparisons revealed training load was lower in week one in comparison with subsequent training weeks. (-408 AU, CI -741 to -75 AU, *P*=0.014; -340 AU, CI -493 to -187 AU, *P*<0.001; -302 AU, CI 502 to 101 AU, *P*=0.003; -262 AU, CI -446 to -79 AU, *P*=0.004; for week 1 vs week 2, week 3, week 4 and week 5, respectively). However, the number of days trained in week 1 was fewer (Figure 5.1).

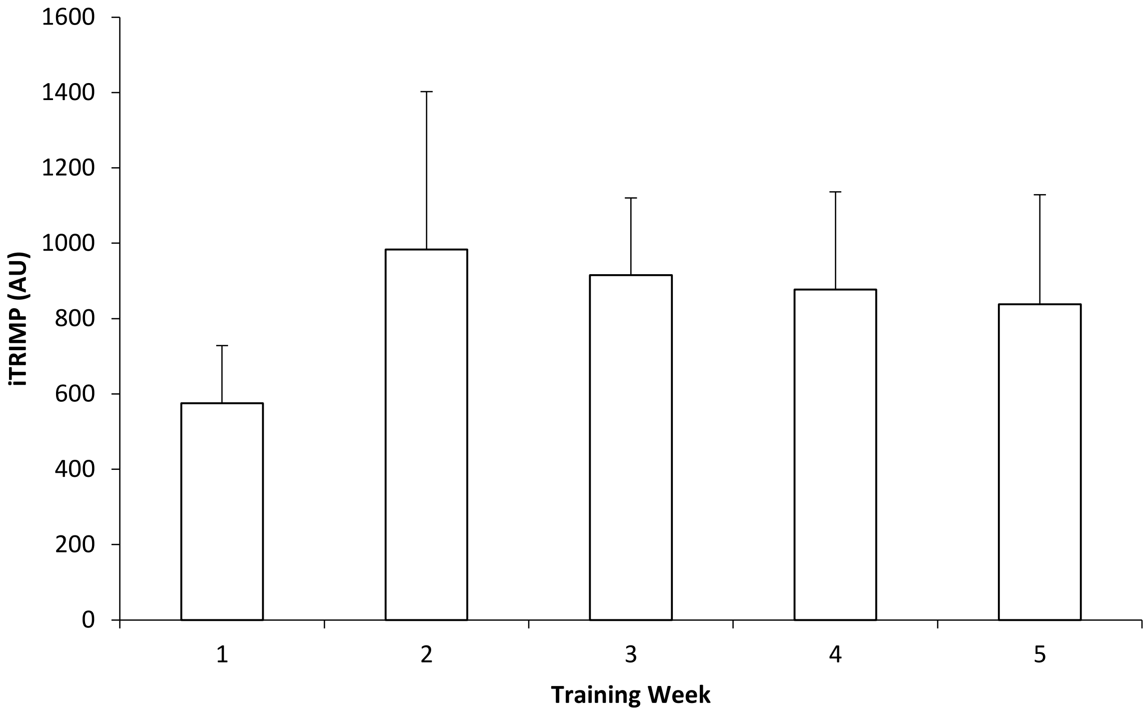


Figure 5.2. Internal Training load (iTRIMP) across a 5 week pre-season training period in elite category two English academy football players (F=11.82, *P*=<0.001, η_P^2 =0.54). Data expressed as mean ± SD. Note: week 1 training days n=3, week 2 training days n=6, all other weeks training days n=5. n=11 participants.

5.3.2 Well-being responses

Small changes in perceptions of motivation were evident between training weeks (Table 5.4). Pairwise comparisons revealed lower motivation in week 1 in comparison with week 2 and week 4 (-0.8 AU, CI -1.4 to -0.2 AU, *P*<0.05; -0.9, CI -1.4 to -0.2 AU, *P*<0.05; for week 2 and week 4 vs. week 1). In addition, perceptions of motivation were lower in week 5 in comparison with week 2, week 3 and week 4. (-1.0 AU, CI -1.6 to -0.3 AU, *P*<0.05; -0.8 AU, CI -1.5 to -0.1 AU, *P*<0.05; -1.0 AU, CI -1.6 to -0.4 AU, *P*<0.05; for week 2, week 3 and week 4 vs. week 5). Trivial changes in perceptions of sleep, recovery, appetite, fatigue, stress and muscle soreness were observed (Table 5.4).

Table 5.4. Weekly WQ responses throughout a five week pre-season training period in elite category two English academy football players.

	Week 1	Week 2	Week 3	Week 4	Week 5
Motivation	0.9 ± 0.7	1.7 ± 0.8*^	1.5 ± 0.9^	1.8 ± 0.7 *^	0.7 ± 0.7
Sleep Quality	0.6 ± 1.0	0.5 ± 0.8	0.3 ± 0.6	0.3 ± 0.9	0.2 ± 0.9
Recovery	0.4 ± 1.1	0.5 ± 0.6	0.1 ± 0.6	0.4 ± 0.5	-0.1 ± 0.8
Appetite	0.9 ± 0.9	0.8 ± 0.8	0.6 ± 0.8	0.8 ± 0.8	0.4 ± 0.7
Fatigue	-0.3 ± 1.0	-0.2 ± 0.5	0.0 ± 0.5	-0.1 ± 0.4	0.1 ± 0.8
Stress	-0.8 ± 1.0	-0.6 ± 1.1	-0.5 ± 1.0	-0.8 ± 1.0	-0.5 ± 0.6
Muscle Soreness	0.0 ± 0.7	-0.3 ± 0.6	0.1 ± 0.6	-0.1 ± 0.5	0.4 ± 1.1

Data are expressed as the group mean ± SD of the individual's weekly mean response for perceptions of motivation to train ($F_{(1,4)}$=4.04, *P*=0.006, η_p^2 =0.24), sleep quality ($F_{(1,4)}$=0.50, *P*=0.74, η_p^2 =0.04, recovery ($F_{(1,4)}$=1.12, *P*=0.36, η_p^2 =0.08), d) appetite ($F_{(1,4)}$=0.80, *P*=0.53, η_p^2 =0.06), e) fatigue ($F_{(1,4)}$=0.63 *P*=0.64, η_p^2 =0.05), f) stress ($F_{(1,4)}$=0.22 *P*=0.93, η_p^2 =0.02), g) muscle soreness ($F_{(1,4)}$=1.15 *P*=0.35, η_p^2 =0.08) in each training week. n = 11. *denotes lower in comparison with week 1. ^ Denotes lower in comparison with week 5.

5.3.3 Physical performance responses

Anthropometrics and physical performance tests pre training and post training are presented in Table 5.5. A trivial decrease in body mass (-0.1 ± 1.1 kg, CI -0.7 to 0.7 kg) and a moderate decrease in skinfolds (-6.4 ± 3.4 mm, CI 8.7 to -4.1 mm) were observed post training in comparison with pre training (Table 5.5). Small improvements in $\dot{V}O_2$ peak (1 ± 3 $ml.kg.bm.^{-1}$, CI -2 to 3 $ml.kg.bm.^{-}1$) and S4 (0.5 ± 0.9 $km{\cdot}hr^{\cdot-1}$, CI -0.1 to 1.1 $km{\cdot}hr^{\cdot-1}$) were evident post training in comparison with pre training (Table 5.5). Moderate improvements in MAS were observed post training in comparison with pre training (Table 5.5; 0.9 ± 0.6 $km.hr.^{-1}$, CI 0.6 to 1.3 $km{\cdot}hr^{\cdot-1}$). A moderate decrease in 30 m sprint performance (0.17 ± 0.13 s, CI 0.09 to 0.26 s), a small decrease in AAT (0.11 ± 0.18 s, CI -0.01 to 0.23 s) and a trivial decrease in CMJ (-1 ± 3 cm s, CI -3 to 0 cm), was evident post training in comparison with pre training (Table 5.5).

Table 5.5. Anthropometrics and physical performance tests prior to and following a five week pre-season training period in elite category two English academy football players.

	Pre Training	Post Training	*P* Value	Cohen's *d*
body mass(kg)	70.3 ± 4.9	70.2 ± 4.6	0.93	0.02
Skinfolds (kg)	60.4 ± 16.1	54.0 ± 14.7	<0.001	0.67
$\dot{V}O_2$ peak (ml.kg.bm.$^{-1}$)	61 ± 3	62 ± 3	0.53	0.33
MAS (km·hr^{-1})	18.7 ± 1.1	19.6 ± 0.8	<0.001	0.94
S4 (km·hr^{-1})	13.5 ± 1.0	14.0 ± 0.7	0.07	0.58
30 m sprint (s)	4.17 ± 0.17	4.34 ± 0.17	0.001	1.00
AAT (s)	8.20 ± 0.27	8.31 ± 0.26	0.07	0.42
CMJ (cm)	44 ± 6	43 ± 6	0.21	0.17

Mean ± SD, 95 %, *P* value and Cohens *d* for body mass, the sum of eight skinfolds (skinfolds), peak oxygen uptake ($\dot{V}O_2$ peak), maximal aerobic speed (MAS), speed at a fixed blood-lactate concentration of 4 mmol·l^{-1} (S4), 30 m sprint tests, the arrowhead agility test (AAT) and countermovement jump (CMJ). n=11.

A moderate decrease in HR_{ex} was observed as pre-season progressed. Post-hoc analysis revealed a moderate decrease in HR_{ex} from week 2 to 5 (-8 ± 5 b·min^{-1}, CI -1 to 18 b·min^{-1}, *P*=0.08, Figure 5.3). A large increase in HRR was evident as pre-season progressed. Pairwise comparisons revealed increases in HRR in week 4 and week 5 in comparison with week 2 (24 ± 9 b·min^{-1}, CI 13 to -35 b·min^{-1}, *P*<0.001 and 19 ± 6 b·min^{-1} CI 5 to 34 b·min^{-1}, *P*=0.02, for week 4 vs week 2 and week 5 vs week 2, respectively, Figure 5.4)

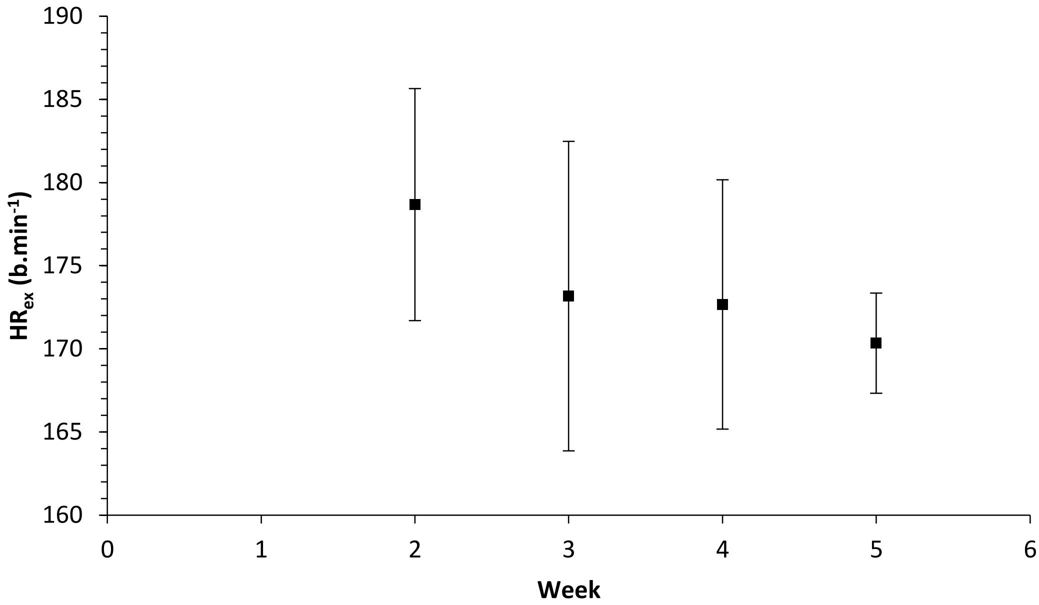


Figure 5.3. Changes in Exercising HR (HR_{ex}) during the final 30 seconds of stage four of the Heart Rate Interval Monitoring System (HIMS) between weeks during a five week pre-season training period in elite English youth football players. ($F_{3,15} = 2.58$, P=0.09; η^2_p 0.34), n=6. (Week 2 day 8, Week 3 day 15, week 4 day 22 and week 5 day 29)

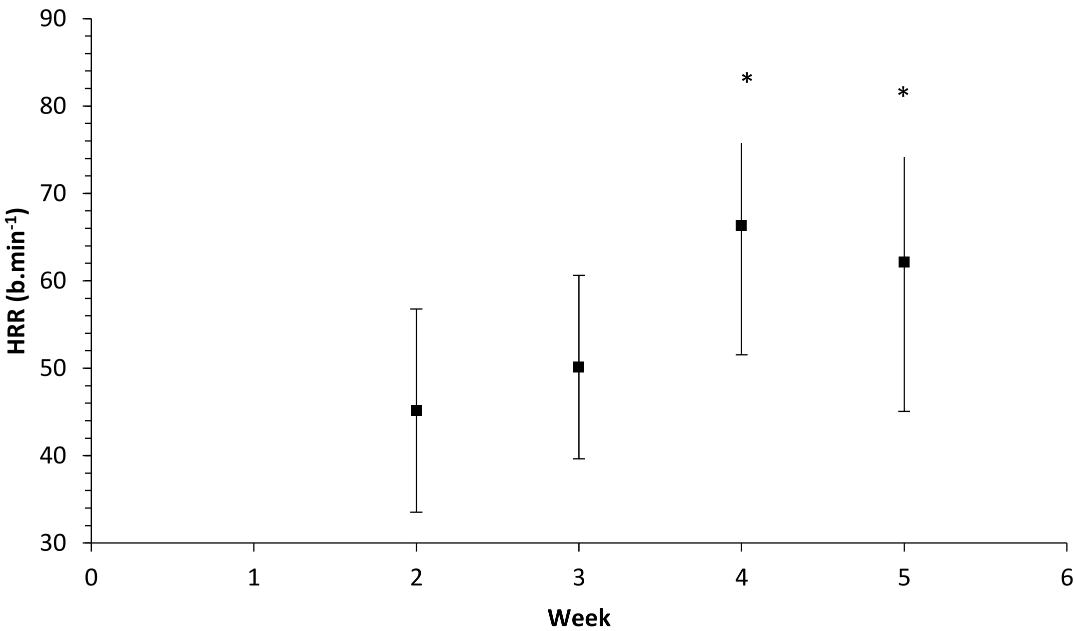


Figure 5.4. Changes in heart rate recovery (HRR) during the 60 seconds recovery period following stage four of the Heart Rate Interval Monitoring System (HIMS) between weeks during a five week pre-season training period in elite category two English academy football players ($F_{3,15} = 14.47$, P<0.001; η^2_p 0.74), n=6. (Week 2 day 8, Week 3 day 15, week 4 day 22 and week 5 day 29). * denotes an increase in HRR in comparison with week 2.

5.3.4 Dose response relationships

Trivial to small correlations (r=-0.21 to 0.19) between WQ responses the day following one day, cumulative two day, cumulative three day and cumulative seven day training loads were evident (Table 5.6). A moderate relationship (r=0.41) between training load and S4 was observed (Figure 5.5).

Table 5.6. Correlation between internal training load (iTRIMP) and well-being questionnaire (WQ) responses during a five week pre-season training period in elite category two English academy football players.

	n	motivation	sleep quality	Recovery	Appetite	fatigue	stress	muscle soreness
1 day load	69	0.03	-0.06	-0.12	0.19	0.06	0.09	-0.09
CI		-.20 – 0.30	-0.28 – 0.17	-0.29 – 0.06	-0.09 – 0.42	-0.12 – 0.23	-0.14 – 0.29	-0.27 – 0.09
2 day load	131	0.00	-0.09	-0.13	0.06	-0.06	-0.13	-0.04
CI		-0.18 – 0.19	-0.24 – 0.05	-0.25 - -0.02	-0.11 – 0.23	-0.20 – 0.06	-0.26 – 0.02	-0.19 – 0.10
3 day load	132	0.03	-0.06	-0.12	0.16	-0.13	-0.13	-0.04
CI		-0.17 – 0.23	-0.19 – 0.09	-0.27 – 0.03	-0.02 – 0.34	-0.29 – 0.03	-0.26 – 0.05	-0.19 – 0.12
week load	127	0.02	-0.12	-0.04	0.19	0.09	0.11	-0.01
CI		-0.16 – 0.21	-0.26 – 0.02	-0.18 – 0.11	-0.01 – 0.37	-0.06 – 0.23	-0.05 – 0.25	-0.17 – 0.16
cumulative load	158	-0.09	-0.21	-0.14	-0.06	0.17	0.05	0.13
		-0.25 – 0.08	-0.35 to 0.06	-0.28 – 0.03	-0.21 – 0.09	-0.01 – 0.31	-0.10 – 0.18	-0.03 – 0.27

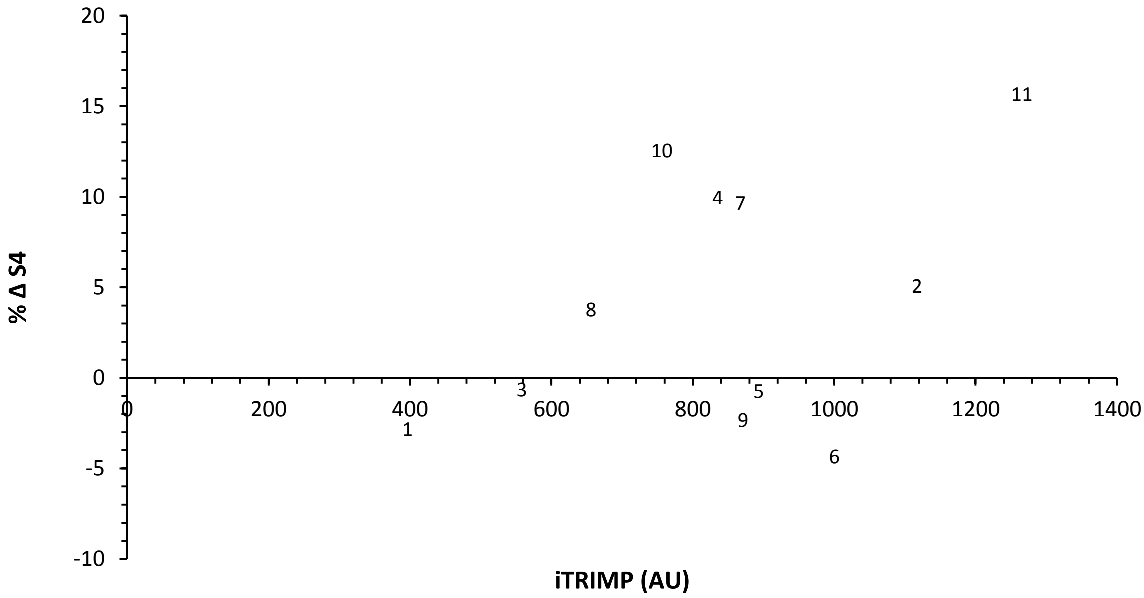


Figure 5.5. Dose-response relationship between iTRIMP and speed at a fixed blood-lactate concentration of 4 mmol·l^{-1} (S4) during a five week pre-season training period in elite category two English academy football players. Participants 1 to 11.

5.3.5 Single subject case studies

Individual responses are presented for S4 in Figure 5.6 showing a tendency for an increase in S4 in the participants who were less fit at the start of the pre-season period. Physical performance changes for participant 6 and participant 10 are presented in Table 5.7. Participant 6 had an almost certainly lower CMJ, a very likely slower ATT performance and a likely lower 30 m sprint time. No other changes in physical performance measures were considered substantial (Table 5.7). Participant 10 had almost certain improvement in MAS, S4 and a likely improvement in CMJ. None of the changes in other physical performance measures were considered substantial (Table 5.7).

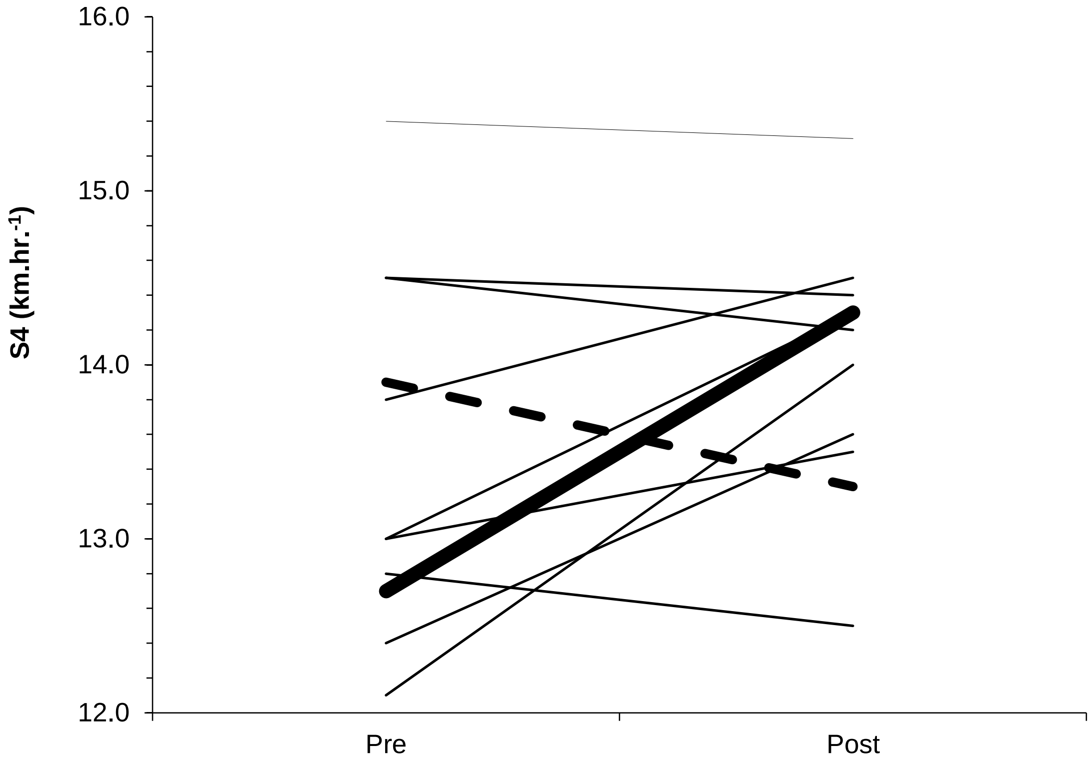


Figure 5.6. Individual changes in speed at a fixed blood-lactate concentration of 4 mmol·l^{-1} (S4) prior to and following pre-season training in elite English youth football players. Participant 6 (dashed line) participant 10 (thick black line).

Table 5.7. Physical performance tests prior to and following pre-season training in participant 6 and participant 10.

		Pre	Post	Change	Likely limits (-ve / trvial / +ve)	Description
Participant 6						
	$\dot{V}O_2$ peak (ml·kg^{-1}·min^{-1})	61	61	0	40/20/40	No Change
	MAS (km·hr^{-1})	18.5	19.0	0.5	2/28/70	possibly / may not be faster
	S4 (km·hr^{-1})	13.9	13.3	-0.6	8/20/72	possibly / may not be faster
	30 m sprint (s)	4.15	4.24	0.09	85/15/1	Likely / probably slower
	CMJ (cm)	51	44	-7	99/1/0	almost certainly lower
	AAT (s)	8.02	8.33	0.31	98/2/0	Very likely slower
Participant 10						
	$\dot{V}O_2$ peak (ml·kg^{-1}·min^{-1})	57	59	2	22/18/60	Possibly may not be higher
	MAS (km·hr^{-1})	16.0	18.5	2.5	0/0/100	Almost certainly faster
	S4 (km·hr^{-1})	12.8	14.3	1.5	0/1/99	Almost certainly faster
	30 m sprint (s)	4.09	4.15	0.06	66/31/2	Possibly may not be slower
	CMJ (cm)	37	41	4	0/8/91	Likely/ probably higher
	AAT (s)	8.27	8.38	0.11	64/30/5	Possibly may not be slower

Peak oxygen uptake ($\dot{V}O_2$ peak), maximal aerobic speed (MAS), speed at a fixed blood-lactate concentration of 4 mmol·l^{-1} (S4), 30 m sprint tests, the arrowhead agility test (AAT) and countermovement jump (CMJ). Typical error used in analysis: $\dot{V}O_2$ peak 4.8 %; MAS 1.4 % (Weltman et al., 1990); S4 2.4 % (Prettin et al., 2013); 30 m Sprint 0.8 % (D'Auria et al., 2006); CMJ 3.2 %; AAT 0.9 %; (Harsley et al., 2010). SWC used in analysis based on 0.2 of the between participant SD of pre-season mean values (n=11): $\dot{V}O_2$ peak 1 ml·kg^{-1}·min^{-1}; S4 0.3 km·hr^{-1}; MAS 0.3 km·hr^{-1}; 30 m sprint 0.04 s; AAT 0.07 s; CMJ 1.5 cm. Likely limits: percentage chance of the value is negative (-ve)/ trivial/ positive (+ve).

Participant 6 had a higher weekly internal load in comparison with participant 10 (1000 AU vs 758 AU, Figure 5.7a). Participant 6's highest load was two days prior to testing (Figure 5.7a) which was concomitant with deteriorations in perceptions of well-being (recovery, fatigue and muscle soreness) on the subsequent testing days. Except for the deteriorations in perceptions of well-being on the testing days, well-being remained relatively constant throughout the pre-season period (Figure 5.7b, Figure 5.7c and 5.7d). Participant 10 had more fluctuations in perceptions of well-being over the pre-season period (Figure 5.7b, Figure 5.7c and 5.7d).

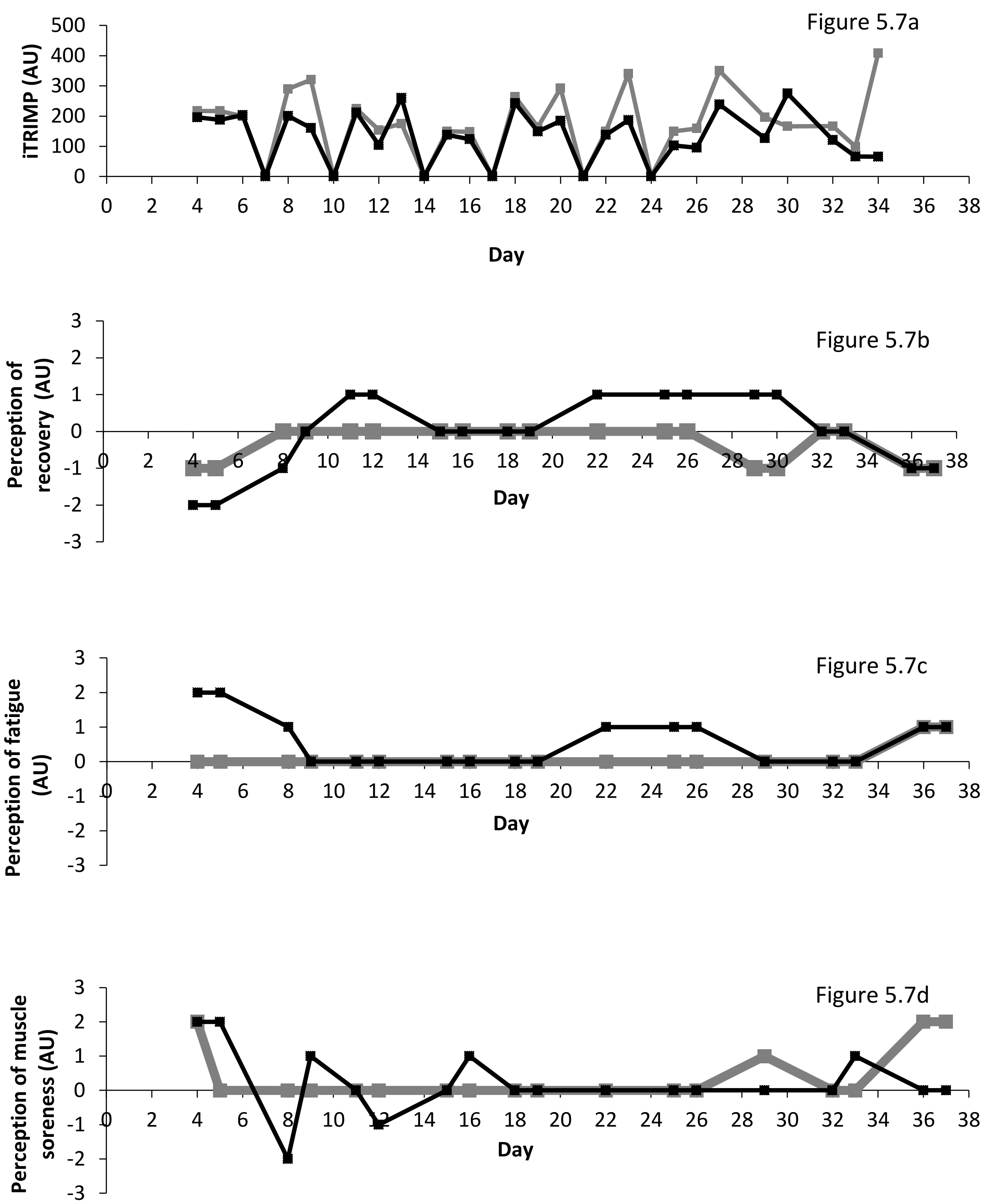


Figure 5.7 (a) Internal training load, (b) Perceptions of recovery, (c) Perceptions of fatigue and (d) Perceptions of muscle soreness across the five week pre-season training period in participant 6 and participant 10. Participant 6 (grey), participant 10 (black).

An almost certain increase in HRR in participant 10 was observed from day 8 to day 15, (37 b·min^{-1} to 48 b·min^{-1}, (0/0/100)) and from day 15 to day 22 (48 b·min^{-1} to 60 b·min^{-1}, (0/0/100)) respectively (Figure 5.8). A likely decrease in HR_{ex} was reported between day 15 and day 22 (190 b·min^{-1} to 183 b·min^{-1}, (0/0/91) and an almost certain decrease in HR_{ex} from day 22 to day 29, and 183 b·min^{-1} to 171 b·min^{-1}, (0/0/100) was observed (Figure 5.8). Unfortunately, due to data errors only two submaximal HR assessments were carried out in participant 6.

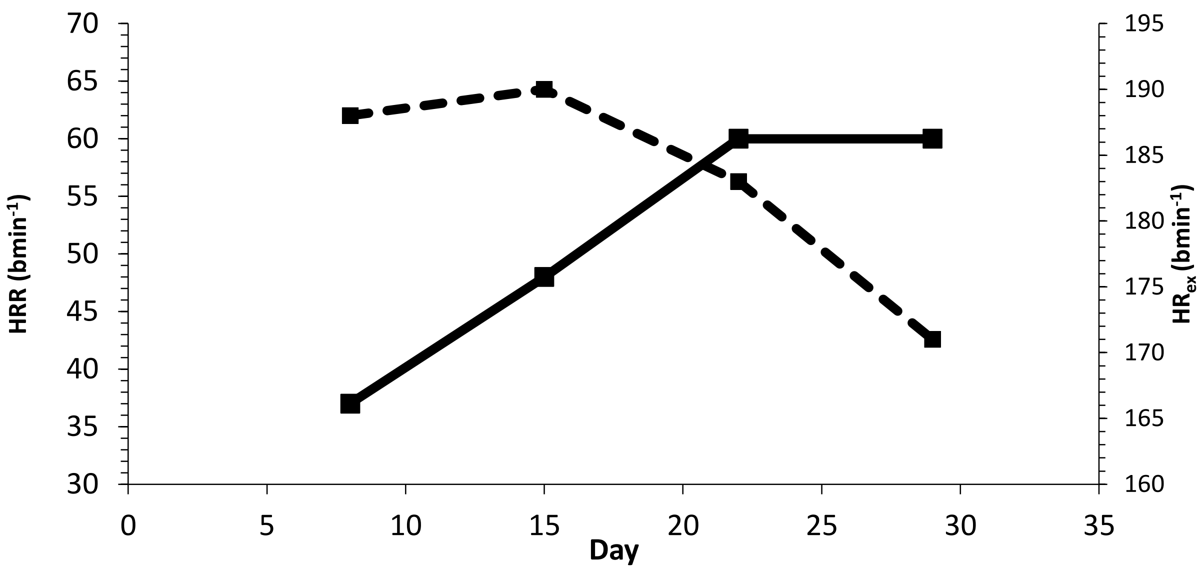


Figure 5.8. Changes in heart rate recovery (HRR) during the 60 seconds recovery period following stage four of the Heart Rate Interval Monitoring System (HIMS; black line) and changes in exercising heart rate (HR_{ex}) during the final 30 seconds of stage four of the Heart Rate Interval Monitoring System (HIMS; dashed line) between weeks during a five week pre-season training period in participant 10.

5.4 Discussion

The main finding of the study was that, the lack of a reduction in well-being responses, prior to each training session during a pre-season period, was associated with small to moderate improvements in aerobic performance. However, small to moderate impairments in selected neuromuscular performance assessments (30 m sprint and AAT) were observed. Internal training load and WQ items (perceptions of: sleep quality, recovery, appetite, fatigue, stress and muscle soreness) were consistent across weeks two, three, four and five with no negative WQ responses evident. Well-being, determined using the WQ, assessed prior to each training session showed trivial to small relationships with internal training load.

In the present study player well-being was assessed prior to each training session. The small to trivial associations between internal training load and the WQ could be a result of small variation in the internal loads between training sessions in which players may not have been exposed to high enough training loads to elicit reduced well-being responses previously associated with high training loads (chapter 4). In addition, the WQ was only completed on the morning of training days and was not assessed on rest days which usually followed the highest training or match load days. Therefore, the trivial to small associations between internal load and WQ responses and lack of any negative WQ responses across the weeks likely reflect that well-being was restored prior to training.

A preserved well-being prior to training sessions was associated with small to moderate improvements in aerobic performance over the pre-season period similar to those previously reported in elite youth players (McMillan et al., 2005a) and elite senior players (Manzi et al., 2013). In addition, a moderate decrease in HR_{ex} and a large increase in HRR were observed, as pre-season training progressed, such as have previously been associated with improvements in aerobic fitness (Buchheit, 2014, Daanen et al., 2012). Given that the internal load remained similar across weeks, improvements in aerobic fitness as pre-season progressed could reflect the effective progressive overload of external workloads (Gamble, 2006).

It is noted that the improvements in S4 in the present study (13.5 ± 1.0 vs. 14.0 ± 0.5 $km \cdot hr^{-1}$, small effect) were of a smaller magnitude compared with those previously reported in elite youth (S4: 13.6 ± 0.2 vs. 14.7 ± 0.2 $km \cdot hr^{-1}$, very large effect; McMillan et al., 2005a) and elite senior players (S4: 13.7 ± 2.0 vs. 14.7 ± 1.5 $km \cdot hr^{-1}$, moderate effect; Manzi et al., 2013) during the pre-season period. Hence, a greater internal load in the present study may have elicited further improvements in aerobic performance. However, the internal training load (iTRIMP) in the present study was higher in comparison with a previous study in elite senior players (838 ± 246 AU vs. 644 ± 224 AU; Manzi et al., 2013) therefore the smaller magnitude of change may reflect players in the present study approaching their genetic limit (Faude et al., 2014).

A limitation to the present study is that external workload could not be measured. The use of micro-tracking technology is expensive and not available to many category two, three and four academies. Previously, no difference in both internal (% HR_{max}) or external (Total distance and high intensity distance >19.8 $km \cdot hr^{-1}$) training load between weeks were observed across a pre-season period in elite senior players, however, no measures of physical performance were reported (Malone et al., 2015a). The aim of the pre-season period, in the present study, was to increase the external loads players were exposed as pre-season progressed. It is plausible that external training load increased across pre-season resulting in internal training load remaining constant across weeks due to improvement in aerobic fitness.

The small to moderate impairments in neuromuscular performance observed in the present study could reflect the high aerobic training load which has previously been associated with impaired neuromuscular performance which could reflect inadequate physical recovery (Faude et al., 2014) or low volumes of neuromuscular training (Loturco et al., 2015). Given that the WQ responses did not deteriorate as the pre-season progressed, it is speculated that neuromuscular training was not adequate to maintain or elicit improvements in neuromuscular performance. This may highlight that a greater focus on appropriate neuromuscular training is required to maintain or elicit improvements in neuromuscular performance capacity (Loturco et al., 2016) in elite youth players to ensure players can excel during critical high intensity actions (Silva et al., 2015).

The trivial to moderate dose response relationships between internal load and the WQ and change in aerobic performance are also influenced by several individual confounding factors. Changes in aerobic performance had confidence intervals which overlapped zero (VO2 peak, -2 to 3 ml·kg·bm^{-1} and S4, -0.1 to 1.1 km·hr$^{\cdot -1}$), highlighting the uncertainty in the improvements in aerobic performance. In addition, the moderate relationship between changes in S4 and iTRIMP had wide confidence intervals. The uncertainty in these findings are likely to reflect the complex interactions between gaining fitness, adequate recovery and changes in training load during the pre-season period are determined by a multitude of individual confounding factors including initial level of fitness (Manzi et al., 2009b), training history (Silva et al., 2016) and genetic potential (Faude et al., 2014).

The lower dose response relationship (r=0.41 vs r=0.64) observed in the present study in comparison with a previous study conducted over a pre-season period in elite senior players (Manzi et al., 2013) is likely to reflect the heterogeneous characteristics of the players. Participant 6 had a lower weekly internal training load in comparison with participant 10 (758 AU vs 1000 AU) yet participant 10 improved several aspects of physical performance (aerobic and CMJ) whilst participant 6 did not. The improvements in participant 10 are likely to reflect the initial low levels of fitness (Manzi et al., 2009b, McMillan et al., 2005a) a result of the participant returning from a 6 month injury lay off. The lack of improvement in aerobic performance observed with a high training load in participant 6 is likely to indicate adherence to an off-season training plan (Silva et al., 2016), higher initial aerobic fitness and the participant shifting closer to their genetic potential (Faude et al., 2014).

Levels of fitness could also influence well-being following a training stress and the adaptation of each player. Players with higher levels of fitness will recover more rapidly from training stress (Bishop et al., 2008, Rampinini et al., 2011). Participant 10 had perturbations in WQ responses demonstrating training induced changes in the stress-recovery balance and subsequent improved aerobic performance (Issurin, 2010). Conversely, the high load experienced by participant 6 with very few fluctuations in WQ response might reflect participant 6's high levels of initial fitness and adequate recovery through the period.

Interestingly, participant 6 presented with a decrease in several aspects of physical performance (S4, CMJ, Sprints) pre to post training which is unlikely to indicate NFOR given the adequate WQ responses throughout the five week training period (Faude et al., 2014). However, impaired physical performance could reflect acute physical fatigue on the day of testing (Meeusen et al., 2013) considering participant 6 was exposed to their highest load two days prior to testing, with concomitant negative perceptions of well-being on post testing days. Therefore, a limitation to maximal physical performance tests is that they do not dichotomise the influence of acute and longer term training responses and only provide a snap shot of the player on that given day.

Submaximal physical performance tests may be useful to assess aerobic fitness on a more regular basis as a means to addressing the limitations of infrequent use of maximal physical performance tests. An almost certain increase in HRR and increase in HR_{ex} from week 2 to week 3 and from week 4 to week 5 were observed in participant 10. These were concomitant with positive WQ responses and therefore are likely to reflect an improvement in aerobic fitness.

The use of HR_{ex} and HRR to assess changes in physical performance over a period may be limited due to the inability to dichotomise fitness and fatigue. A decrease in HR_{ex} has been associated with both improvements in aerobic fitness (Brink et al., 2012, Schmikli et al., 2011) and NFOR (Le Meur et al., 2013). Similarly, a faster HRR has been associated with both improvements in aerobic fitness (Lamberts et al., 2009, Lamberts et al., 2010) and NFOR. (Aubry et al., 2015). This highlights that measures of HR_{ex} and HRR may be unable to dichotomise the fitness fatigue relationship and that the triangulation of supplementary monitoring assessments, including individual training load, perceptions of well-being, submaximal HR responses and coach observations (Aubry et al., 2015) are required to assess training response. Hence, an approach that integrates art and science could assist in the management of elite youth football players on an individual level.

In summary, elite English youth football players preserved well-being prior to each training session during the pre-season period. The preservation of well-being prior to sessions was associated with improvements in aerobic performance, which may be indicative of a balance between stress and recovery. However, neuromuscular performance was impaired likely due to an inadequate neuromuscular stimulus. Individual confounding factors such as the complex interactions between internal load, gaining physical fitness and recovery highlight the need to assess well-being and physical performance responses frequently on an individual level.

CHAPTER 6

6.0 Perceptions of well-being and physical performance in English elite youth footballers across a season.

Chapter five highlighted that elite English youth football players' well-being was preserved prior to each training session during a low volume, high intensity pre-season period that focused on physical characteristics. Collectively, preserved well-being responses and improvement in aspects of physical performance were indicative of a balance between stress and recovery. Chapter six assesses changes in well-being and physical performance throughout a season when players were exposed to high training volumes.

6.1 Introduction

Section 2.2.1 identified a potential conflict between high training volumes and maximising physical performance in elite English youth football players. The physical development of elite English youth football players is dependent on an adequate training stimulus being accompanied by adequate recovery to induce positive training adaptations (Section 2.4.1). However, the high training volumes elite English youth football players are exposed to stipulated by the EPPP may result in inadequate recovery, often associated with a reduction in well-being and an increased risk of NFOR (section 2.4.5)

In chapter five, elite English youth football player's well-being was preserved prior to each training session during the pre-season period. However, during this period players were exposed to lower training volumes (7.2 ± 1.2 h) compared to the 12-14 h stipulated by the EPPP. High training and competition loads have been linked to players underperforming both technically and tactically (Ekstrand et al., 2004) Verheijen, 2012), an increase in injury rate (Bengtsson et al., 2013, Owen et al., 2015), a reduction in well-being (Faude et al., 2011) and impaired physical performance (Brink et al., 2012, Rollo et al., 2014). The physical and well-being responses to the high training and competition demands stipulated by the EPPP are unknown and may put players at risk of NFOR and / or reduced well-being.

Limited data exists on the periodic tracking of seasonal changes in perceptions of well-being and physical performance in elite youth football players. A season long study in elite German youth players reported that total recovery, assessed using the RESTQ-Sport, deteriorated towards the end of the season, however, no changes were noted in football specific physical performance tests (Faude et al., 2011). Given the introduction of the EPPP, the aim of the present study was to assess seasonal changes in player's perceptions of well-being and physical performance via regular assessment of well-being and analysis of physical performance via a battery of tests.

6.2 Methods

6.2.1 Participants

Fourteen full-time U18 academy outfield football players from a club with category two status volunteered and provided informed consent for the study (mean ± SD: age

17 ± 1 yrs; stature 179 ± 6 cm; body mass 70.8 ± 8.6 kg; sum of eight skinfolds 56.1 ± 11.6 mm, at pre-season). A typical in season training week is presented in Table 6.1.

Table 6.1. Typical weekly in-season training schedule.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	S & C	Prehab	S & C	Prehab			Recovery
		PBS		PBS	PBS	Match	
PM	PBS	PBS		PBS			

S & C, strength and conditioning gym based session; Prehab, prehabilitation session; PBS, squad pitch based session (includes technical, tactical, physical training). Pre-season only one PBS was carried out on Tuesdays and Thursdays. U21 games were carried out in-season on any midweek day altering players training schedule. Players involved in U21 fixtures midweek each missed 5 ± 4 training sessions per season and 2 ± 2 training sessions per season the day following match day.

6.2.2 Exclusion criteria

Players injured for >75 % of training days or players who did not participate in any training during a specified training block (see section 6.2.3) were excluded from the analysis. Three players were excluded based on this criteria (originally n=17).

6.2.3 Study design

The WQ was completed on 1-4 training days per week prior to squad pitch based sessions. Anthropometrics and physical performance tests were carried out at four time points during the season (Figure 6.1).

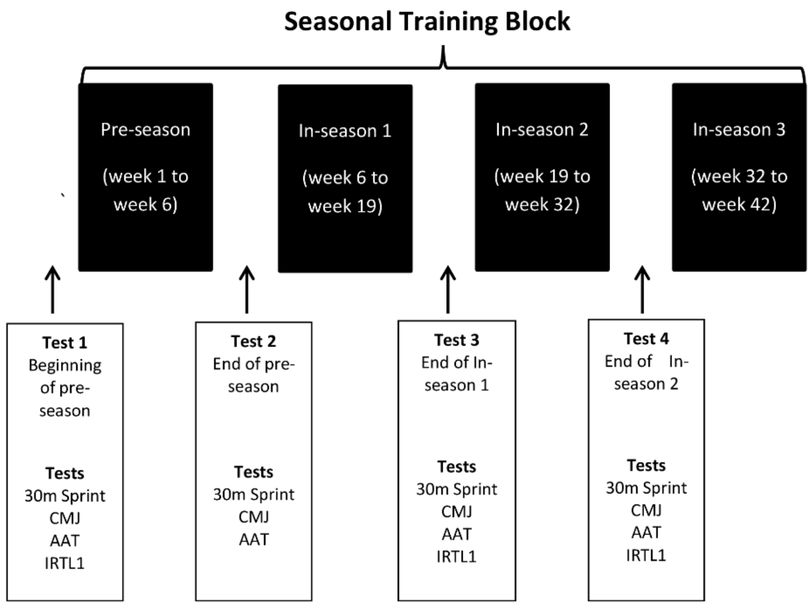


Figure 6.1. Schedule of physical performance tests across the season.

At 9am, prior to training, each player completed the WQ described in section 3.3.1 using a dry wipe marker pen on an A4 laminated white board located above their changing area. During the season the data were reviewed on a daily and weekly basis by sport science staff and coaches to assist decisions on individual player management and training periodisation. However, given the training duration stipulated by the EPPP, players were rarely removed from training and only then when severe decreases in perceptions of well-being were present for several days or weeks. There were two instances of player's training being modified. The data were collated post season and any player who did not train on a given day had that data point removed from the analysis.

Anthropometrics and physical performance testing was carried out following a recovery day at the beginning of pre-season, the end of pre-season, the end of in-season 1 and the end of in-season 2 (Figure 6.1). Anthropometrics were determined using the protocols outlined in section 3.2. The battery of physical performance tests consisted of a 30m sprint, a CMJ, an AAT and Yo-Yo IRT1 which were outlined in sections 3.4.2, 3.4.3, 3.4.4 and 3.4.5, respectively. All players had several years of experience performing the tests and were therefore familiarised with the procedures. No testing took place following in-season 3 due to a number of players being released. Yo-Yo IRT1 was not collected following the end of pre-season due to players training with different squads, a high U18 and U21 fixture demand and time constraints. Players who did not complete the tests at all time points for any given physical performance test were removed from the analysis for that physical performance test only. The resultant participant numbers for each test were: CMJ n=8; 30 m sprint n=12; Yo-Yo IRT1 n=12; AAT n= 12. Prior to all testing procedures players carried out a standardised 10 min warm-up consisting of jogging, running, sprinting and dynamic stretching. All testing was carried out on an indoor 3G pitch. Players wore football boots during all tests except for CMJ where trainers were worn. Testing commenced at the same time of day (10.00 AM) and the order of the tests was identical on all four testing occasions: 1) CMJ; 2) 30 m Sprint; 3) AAT; 4) Yo-Yo IRT1. There was a five minute intermission between each test in which players were requested to stand still.

6.2.4 Statistical analysis

Descriptive data, including squad total training time, actual training exposure, total match time, training availability and match availability, are expressed as mean ± SD for each training block.

Training exposure and questionnaire data were analysed on a per training block basis (Figure 6.1). All training sessions were approximately two hours in duration. Any session that a player participated in was recorded as a two hour session for that individual. Training exposure per week was summated and a mean training exposure for each individual in a given block was calculated. The group mean of each individual's mean training exposure was used in subsequent analysis to assess any difference between the training blocks. A seasonal norm for each individual was determined as the mean score for each WQ item throughout the season. The mean for each individual's responses in a given block of training was also calculated. The difference between the mean score in each block and the seasonal norm for each individual was calculated. The group mean of the difference between the individuals' seasonal norm and the individual's mean score in each block was used in subsequent group analysis to assess differences between training blocks. The questionnaire data and training exposure data were typically not normally distributed. GLM ANOVA, with a bootstrapping procedure of 1000 replications, was used to assess any differences between the training blocks. Confidence intervals were set at 95 % (95 % CI) and were calculated using Tukey pairwise comparisons. The 95 % CI of differences between means that failed to overlap zero were considered statistically significant.

General linear model analysis of variance (GLM ANOVA) with repeated measures was used to assess for changes in physical performance tests during the season. If Mauchley's test of sphericity was violated the degrees of freedom were adjusted using the Greenhouse-Geiser correction (Field, 2000). Where differences were evident, post-hoc pairwise comparisons (Bonferonni adjusted) were used to identify where the differences occurred. Results are reported as mean ± SD and 95 % CI.

Significance for all analysis was set at *P*<0.05. Effect sizes were calculated using partial eta squared (η_p^2), and were defined as: trivial <0.09; small 0.10-0.29; moderate 0.30-0.49; and large >0.5 (Hopkins et al., 2009). All analysis was performed using SPSS.

6.3 Results

Over a period of 283 days there were 194 squad training sessions within 144 days. Table 6.2 summarises the descriptive data for training and match play within each training block throughout the season. A large increase in training exposure was evident as the season progressed (Table 6.2). Post-hoc tests revealed lower training exposure in pre-season compared with all other training blocks (-3.2 h, CI -4.5 to -2.0 h, *P*<0.05; -2.1 h, CI -3.3 to -0.8 h, *P*<0.05; -2.7 h, CI: -3.9 to -1.4 h, *P*<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Table 6.2).

Table 6.2. Descriptive data for training and matches throughout the season and within each block of training for elite category two English academy football players.

	Season	Pre-Season	In- Season 1	In-Season 2	In-Season 3
Training time (h per week)	9.6 ± 2.9	6.8 ± 2.5	10.8 ± 3.1	9.4 ± 2.7	9.8 ± 2.9
Training Exposure (h per week)	8.0 ± 0.7	5.7 ± 1.3	9.0 ± 1.3*	7.8 ± 1.2*	8.4 ± 1.1*
Match time (min)	2017 ± 486	343 ± 124	767 ± 226	491 ± 126	415 ± 234
Training availability (%)	89 ± 6	86 ± 20	87 ± 12	90 ± 11	91 ± 9
Match Availability (%)	93 ± 8	88 ± 27	91 ± 13	95 ± 10	96 ± 8

Training time, total number of hours per week that squad pitch base sessions were carried out; Training exposure, players actual training exposure to squad pitch based sessions taking into account injury, illness, loans, compassionate leave and international duty; Match time, total number of match minutes played; Training availability, percentage of training days player was without injury or illness; Match availability, percentage of match days player was without injury or illness (includes U18 and U21 games). Note that loans, compassionate leave and international duty were classified as available to train or play competitive matches. Data are expressed as mean ± SD, n=14. * denotes significantly different from pre-season ($F_{(3,52)}$=18.06, *P*<0.05; η_p^2 =0.52).

A total of 1362 questionnaire responses were collected throughout the season with each player completing 97 ± 8 (percentage: 68 ± 6 %, range: 83-109) across all training blocks (pre-season, 14 ± 3; in-season 1, 31 ± 4; in-season 2, 34 ± 4 and in-season 3, 20 ± 2). A moderate decrease in perception of motivation to train was observed as the season progressed (Figure 6.2a). Pairwise comparisons revealed moderately lower perception of motivation to train during in-season 3 in comparison with pre-season (-0.66 AU, CI -1.03 to -0.35 AU, P<0.05, Figure 6.2a).

A moderate decline in perceptions of sleep quality was evident as the season progressed (Figure 6.2b). Post-hoc tests revealed moderately lower perceptions of sleep quality during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (-0.30 AU, CI -0.66 to -0.01 AU, P<0.05; -0.44 AU, CI -0.73 to -0.15 AU, P<0.05; -0.54 AU, CI: -0.84 to -0.23 AU, P<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Figure 6.2b). Perceptions of sleep quality were also moderately lower during in-season 2 and in-season 3 in comparison with in-season 1 (-0.14 AU, CI -0.25 to -0.02 AU, P<0.05; -0.24 AU, CI -0.39 to -0.11 AU, P<0.05, for in-season 2, for in-season 3 vs. in-season 1 respectively, Figure 6.2b).

A moderate decrease in perceptions of recovery was evident as the season progressed (Figure 6.2c). Pairwise comparisons revealed moderately lower perceptions of recovery during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (-0.41 AU, CI -0.62 to -0.22 AU, P<0.05; -0.51 AU, CI -0.72 to -0.32 AU, P<0.05; -0.45 AU, CI -0.66 to -0.25 AU, P<0.05; for in-season 1, in-season 2, and in-season 3 vs. pre-season respectively, Figure 6.2c). Perceptions of recovery were also moderately lower during in-season 2 in comparison with in-season 1 (-0.10 AU, CI -0.19 to -0.01 AU, *P*<0.05; Figure 6.2c).

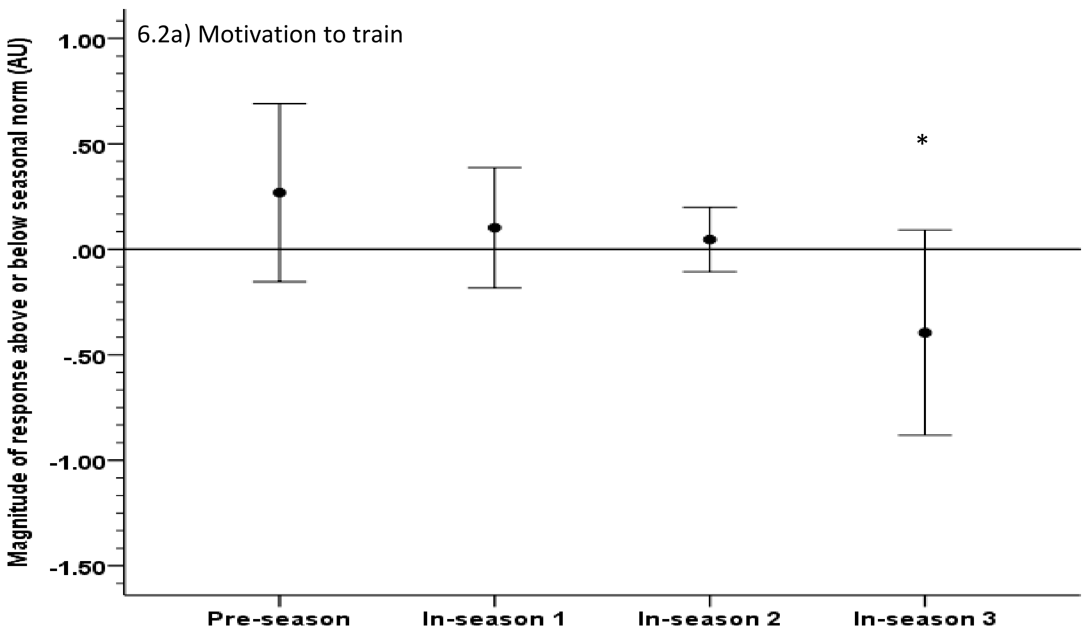
A large decrease in perceptions of appetite was observed as the season progressed (Figure 6.2d). Post-hoc tests revealed a large decrease in perceptions of appetite during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (-0.56 AU, CI -0.87 to -0.27 AU, *P*<0.05; -0.67 AU, CI -0.98 to -0.37 AU, *P*<0.05; -0.71 AU, CI -1.01 to -0.43 AU, *P*<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Figure 6.2d). In addition during in-season 2 and in-season 3 a large decrease in perceptions of appetite was evident in comparison with in-season 1 (-0.11 AU, CI -0.18 to -0.04 AU, *P*<0.05; -0.15 AU, CI -0.24 to -0.07 AU, *P*<0.05, for in-season 2 and in-season 3 vs. in-season 1 respectively, Figure 6.2d).

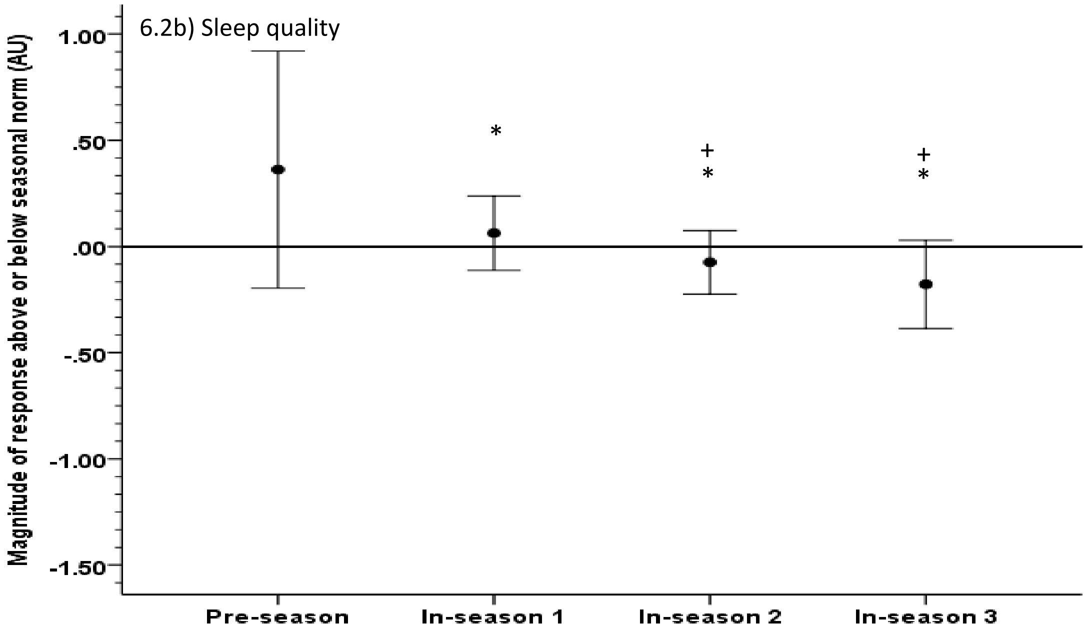
A moderate increase in perceptions of fatigue was evident as the season progressed (Figure 6.2e). Pairwise comparisons revealed moderately higher perceptions of fatigue during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (0.30 AU, CI 0.12 to 0.51 AU, *P*<0.05; 0.33 AU, CI 0.15 to 0.54 AU, *P*<0.05; 0.39 AU, CI 0.21 to 0.59 AU, *P*<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Figure 6.2e).

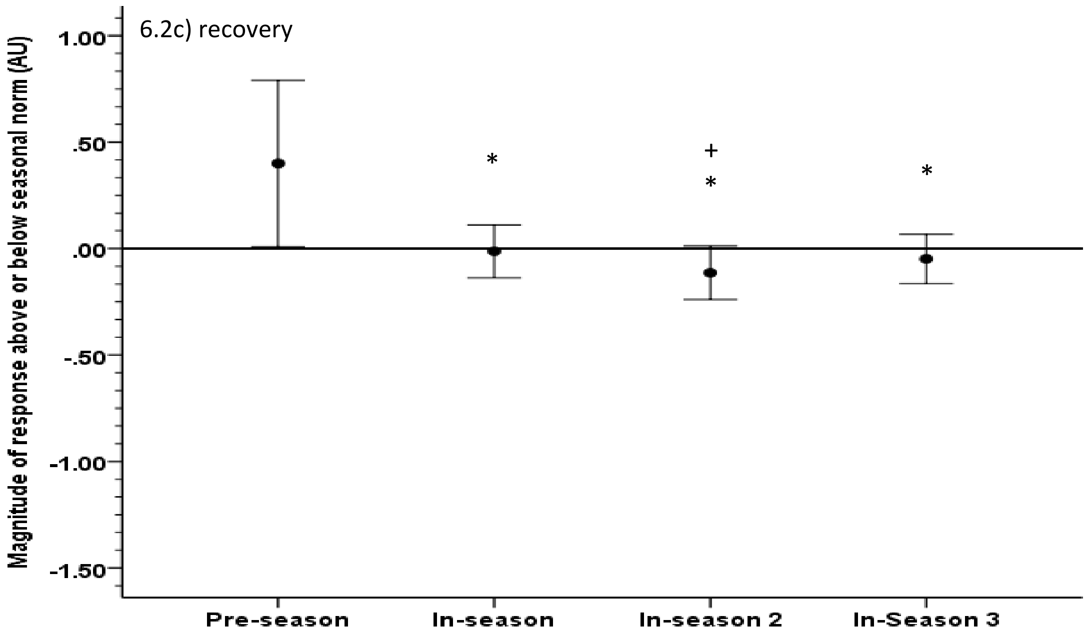
A moderate increase in perceptions of stress was observed as the season progressed (Figure 6.2f). Pairwise comparisons revealed moderately higher perceptions of stress during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (0.54 AU, CI 0.25 to 0.86 AU, *P*<0.05; 0.78 AU, CI 0.48 to 1.12 AU, *P*<0.05; 0.85 AU, CI 0.55

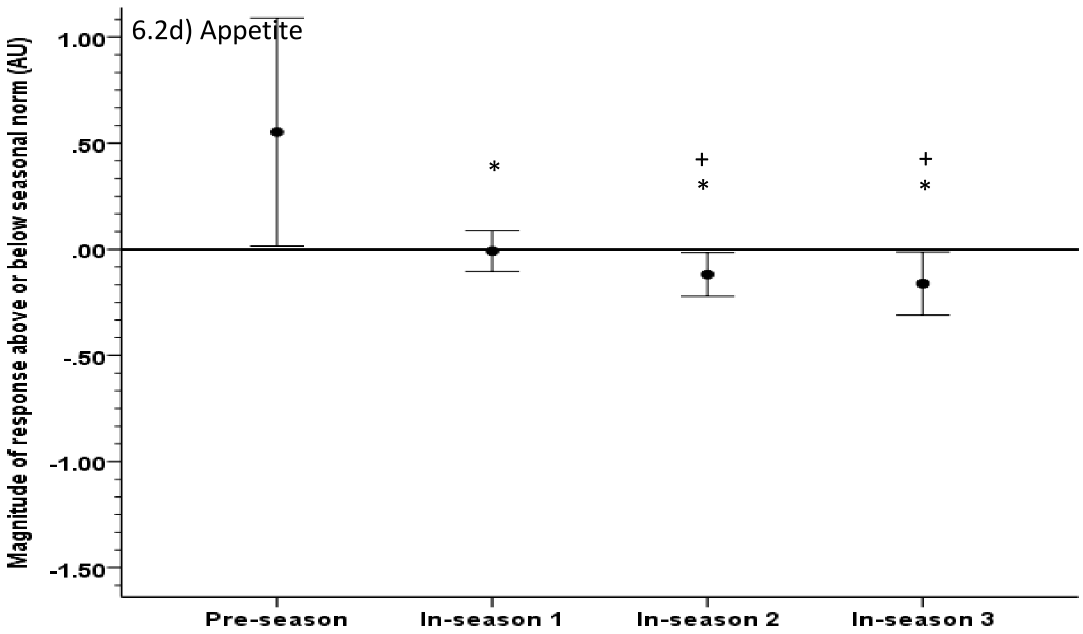
to 1.21 AU, *P*<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Figure 6.2f). In addition moderately higher perceptions of stress were observed during in-season 2 and in-season 3 in comparison with in-season 1 (0.24 AU, CI 0.10 to 0.39 AU, *P*<0.05; 0.31 AU, CI 0.15 to 0.48 AU, *P*<0.05, for in-season 2 and for in-season 3 vs. in-season 1 respectively, Figure 6.2f).

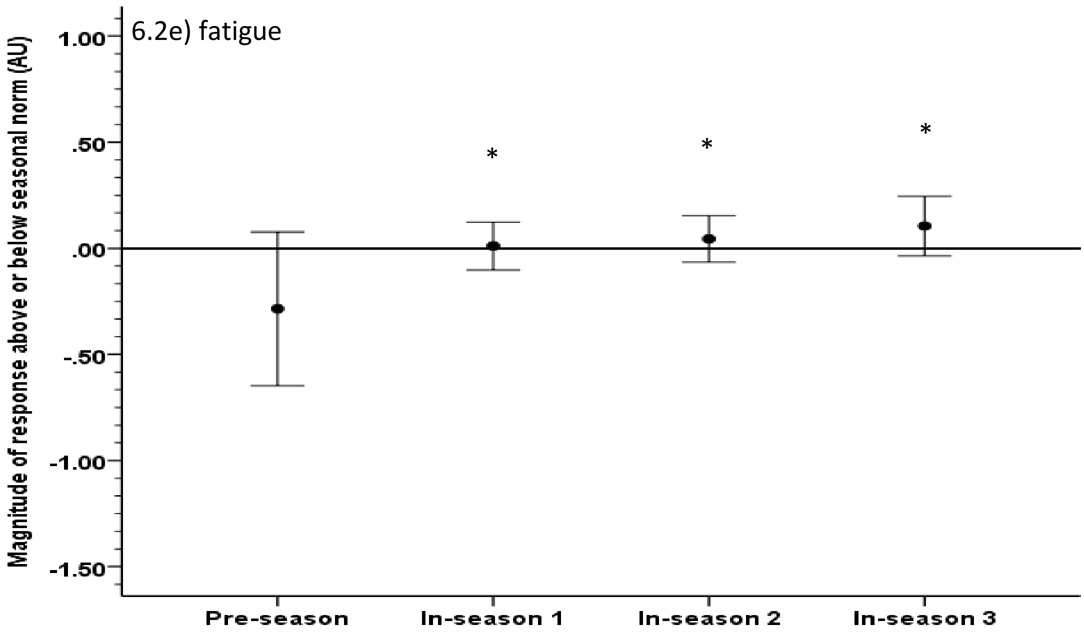
A large increase in perceptions of muscle soreness was evident as the season progressed (Figure 6.2g). Pairwise comparisons revealed a large increase in perceptions of muscle soreness during in-season 1, in-season 2 and in-season 3, in comparison with pre-season (0.40 AU, CI 0.10 to 0.70 AU, *P*<0.05; 0.66 AU, CI 0.36 to 0.95 AU, *P*<0.05; 0.79 AU, CI 0.49 to 1.09 AU, *P*<0.05; for in-season 1, in-season 2 and in-season 3 vs. pre-season respectively, Figure 6.2g). In addition a large increase in perceptions of muscle soreness was observed during in-season 3 in comparison with in-season 1 (0.39 AU, CI 0.09 to 0.69 AU, *P*<0.05; Figure 6.2g).

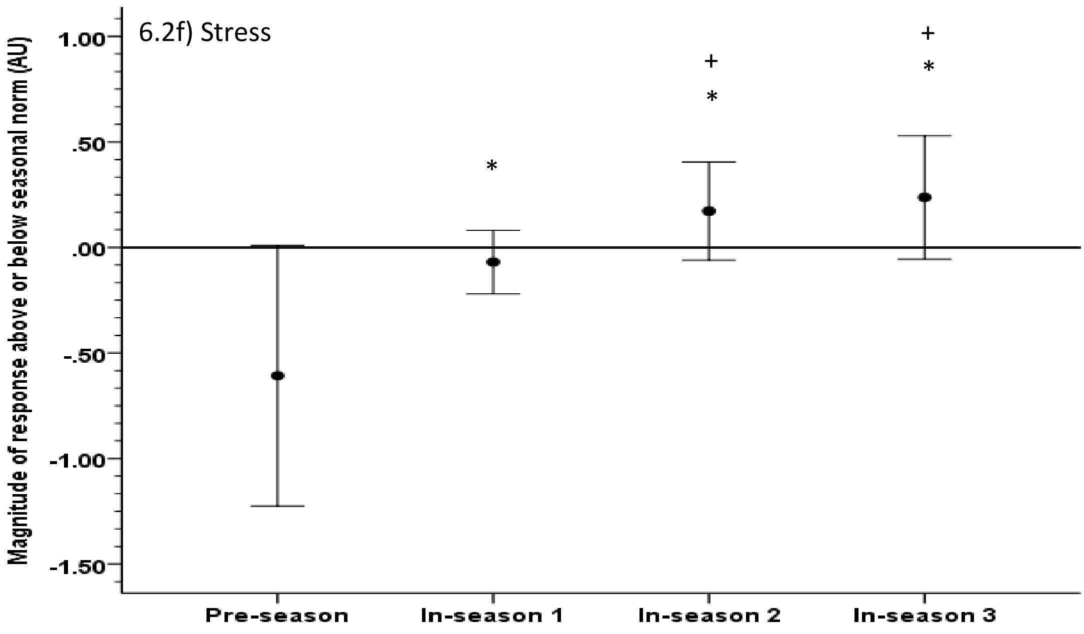



6.2b) Sleep quality
Magnitude of response above or below seasonal norm (AU)
1.00
.50
.00
-.50
-1.00
-1.50
Pre-season
In-season 1
In-season 2
In-season 3
*
+
*
+
*


6.2c) recovery
Magnitude of response above or below seasonal norm (AU)
1.00
.50
.00
-.50
-1.00
-1.50
Pre-season
In-season
In-season 2
In-Season 3
*
+
*
*


6.2d) Appetite
Magnitude of response above or below seasonal norm (AU)
1.00
.50
.00
-.50
-1.00
-1.50
Pre-season
In-season 1
In-season 2
In-season 3


6.2e) fatigue
Magnitude of response above or below seasonal norm (AU)
1.00
.50
.00
-.50
-1.00
-1.50
Pre-season
In-season 1
In-season 2
In-season 3



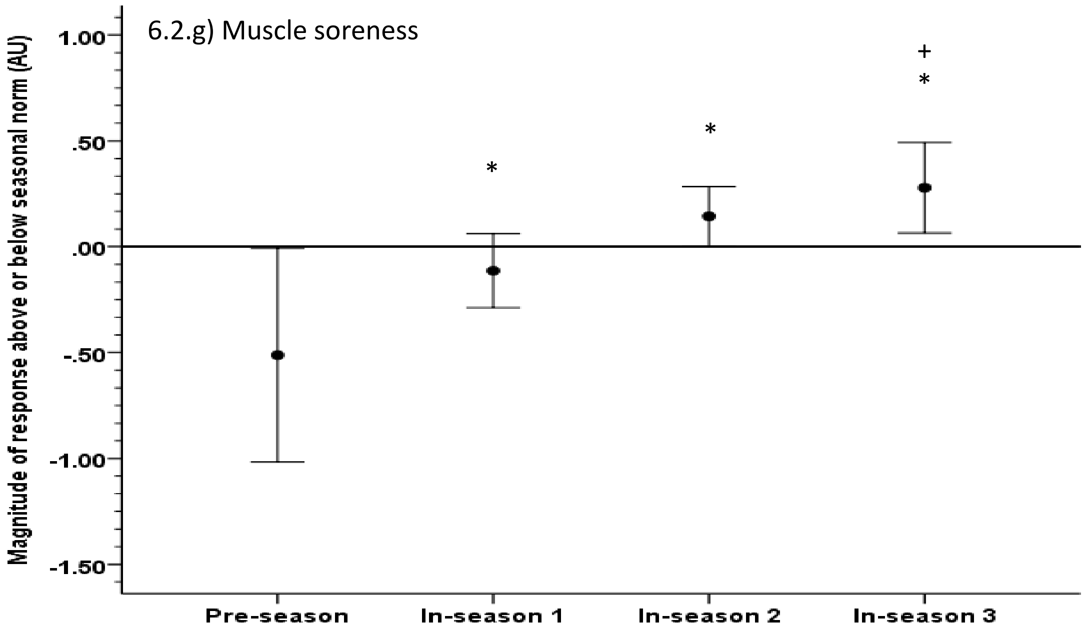


Figure 6.2. Perceptions of: a) motivation to train ($F_{(3,52)}$=8.65, P<0.05; η_p^2 =0.33); b) sleep quality ($F_{(3,52)}$=7.55, P<0.05; η_p^2 =0.30); c) recovery ($F_{(3,52)}$=15.38, P<0.05; η_p^2 =0.47); d) appetite ($F_{(3,52)}$=18.52, P<0.05; η_p^2 =0.52); e) fatigue ($F_{(3,52)}$=9.63, P<0.05; η_p^2 =0.36); f) stress ($F_{(3,52)}$=15.19, P<0.05; η_p^2 =0.47); g) muscle soreness ($F_{(3,52)}$=19.28, P<0.05; η_p^2 =0.53); in each of the four training blocks for elite category two English academy football players. Data presented as the group mean ± SD of the difference between the individual's seasonal norm and the individual's mean score in each training block, n=14. * denotes significantly different from pre-season; + denotes significantly different from in-season 1.

Small to large fluctuations in physical performance throughout the season are presented in Table 6.3. Moderate changes in 30 m sprint speed were evident during the season. Pairwise comparisons revealed that players were moderately slower at the end of pre-season (0.17 s, CI 0.05 to 0.28 s) and at the end of in-season 2 (0.19 s, CI 0.13 to 0.25 s) in comparison with the beginning of pre-season. A large increase in distance covered in the Yo-Yo IRT1 was evident as the season progressed. Pairwise comparisons revealed a large increase in distance covered in the Yo-Yo IRT1 at the end of in-season 1 (334 m, CI 160 to 506 m) and at the end of in-season 2 (947 m, CI 761 to 1132 m) compared to the beginning of pre-season. In addition a large increase in distance covered at the end of in-season 2 in comparison with in-season 1 was observed (613m, CI 505 to 721 m). Through the season changes in AAT performance and CMJ performance were small.

Table 6.3. Physical performance tests at four testing points during a season for elite category two English academy football players.

	n	Beginning of Pre-season	End of pre-season	End of in –season 1	End of in –season 2
30 m Sprint (s)	12	4.14 ± 0.19	4.31 ± 0.18*	4.24 ± 0.22	4.34 ± 0.20*
Agility (s)	12	8.17 ± 0.26	8.27 ± 0.26	8.29 ± 0.26	8.33 ± 0.29
CMJ (cm)	8	44 ± 6	42 ± 6	44 ± 7	43 ± 6
Yo-Yo IRT1 (m)	12	2203 ± 334	N/A	2537 ± 235*	3150 ± 269*^

Data are expressed as mean ± SD for 30 m Sprint ($F_{(3,33)}$=10.12, *P*<0.01; η_p^2 =0.48), Yo-Yo IRT1 ($F_{(2,22)}$=144.84, *P*<0.05; η_p^2 =0.93) AAT ($F_{(3,33)}$=3.44, *P*=0.03; η_p^2 =0.24) CMJ ($F_{(1.39,9.37)}$=1.55, *P*=0.23; η_p^2 =0.18). * denotes different from beginning of pre-season; ^ denotes different from end of in-season 1.

6.4 Discussion

The main finding of the study was that moderate to large deteriorations in perceptions of well-being were evident as the season progressed. In addition a large increase in Yo-Yo IRT1 and a moderate decline in sprint performance were observed at later testing points in the season. The planned training hours in the present study (9.6 ± 2.9

h per week) and actual training exposure (8.0 ± 0.7 h) were still below the 12-14 h per week stipulated by the EPPP for this age group. In addition training exposure was lower in pre-season in comparison with the other training blocks.

The present study provides evidence of reduced perceptions of well-being in English elite youth football players as the football season progresses from pre-season through in-season. Factors influencing well-being in elite youth players include the training and competition load, pressure to earn a contract and relationships with peers, coaches, friends and family (Weedon, 2012). Furthermore neglecting recovery strategies, for example inadequate nutrition and sleep, will further exacerbate the impact of the stress (Barnett, 2006, Reilly and Ekblom, 2005). It is evident that an imbalance between high physical and psychosocial stress and adequate subsequent recovery exists in elite youth football indicating that player education and player management strategies are required. Faude et al., (2014) reported similar decreases in perceptions of well-being in elite German youth football players, with reduced perceptions of recovery and higher perceptions of stress as the season progressed.

It should be acknowledged that there was some uncertainty in the estimate of reduced perceptions of well-being. None of the confidence intervals for the moderate and large changes in perceptions of well-being overlapped zero. However, some of the confidence intervals indicated the lower bound was close to zero. Therefore, some caution should be taken when interpreting these changes. As highlighted in chapter 4 and chapter 5, these confidence interval will be influenced by individual responses to training and non-training stress.

In the present study, the compliance of completing the questionnaires on a daily basis was a limitation. In addition, a possible limitation to the questionnaires could be the potential bias introduced by social desirability leading to players reporting 'fake' positive well-being responses to gain selection (Saw et al., 2015a). Further to this players may report 'fake' negative well-being responses in an attempt to reduce training frequency and intensity (Meeusen et al., 2013). Hence, educating the players on the purpose of the questionnaires and the relationship built between player and the coach is an important aspect to attaining valid information from self-report questionnaires (Gastin et al., 2013, Saw et al., 2015a). Further to this, well-being questionnaires may offer more valuable information on the training response when considered in conjunction with other monitoring assessments (e.g. physical performance tests and internal training load) as highlighted in section 5.4.

The accumulation of stress throughout the season could be influencing physical performance in the present study. Similar findings to the present study were reported following four weeks in-season training in elite German youth players. Improvements in aerobic performance but diminished neuromuscular capabilities, an increased urea concentration and poorer total recovery assessed using the RESTQ-Sport could be interpreted as the early signs of NFOR (Faude et al., 2014). In contrast, Faude et al., (2011) reported no difference in aerobic or neuromuscular performance throughout the season when perceptions of well-being declined. In comparison with the present study, the squad training time was lower in the previous study (~ 6 Vs ~10 h per week) potentially reducing the overall training stimulus and preventing attenuation of physical performance measures.

Another potential rationale for the improvement in endurance and decrement in neuromuscular performance could be a high training and competition volume resulting in a shift towards greater endurance characteristics and a diminished explosive ability. Several researchers have reported a muted explosive neuromuscular response to concurrent training (Dudley and Djamil, 1985, Hakkinen et al., 2003, Hunter et al., 1987, Jones et al., 2013, Loturco et al., 2015). Concurrent speed training and HIIT in addition to high volume football specific training (~10 h), similar to that of the present study elicited improvements in both endurance and neuromuscular performance (Dupont et al., 2004, Wong et al., 2010). Conversely, similar training modalities with a lower training volume (~6 h) have reported improvements in endurance but no changes in neuromuscular performance (Helgerud et al., 2001). In the present study neuromuscular training was not quantified. Therefore, potentially the intensity of the strength and speed training may not have been sufficient to maintain or improve speed. Differences in specificity of training and accumulation of fatigue are potential factors influencing seasonal changes in physical performance. Furthermore differences in maturity (Buchheit and Mendez-Villanueva, 2013), genetics, (Akubat et al., 2012), training exposure (Impellizzeri et al., 2005), level of fitness, training history (Faude et al., 2014), fixture congestion (Gamble et al., 2006) and scheduling of testing (Casajus, 2001) could explain the differences physical performance adaptations in the aforementioned studies. Given the multi-faceted factors influencing each individual’s response to training and competition, an individual approach to the management of each player is important.

Assessing well-being on a daily basis could identify daily fluctuations in well-being and assist the coach and sport science practitioner to make informed decisions with regard to training periodisation and player management. A limitation to the present study is the physical performance testing only gives a snap shot of the players' physical performance on that given day. It is unclear whether each physical performance result represents FOR or NFOR (Meeusen et al., 2013, Nederhof et al., 2008, Nederhof et al., 2006). Additionally the analysis conducted in the present study identifies a global group response. Given the nature of team training this analysis might be useful with regard to the periodisation of team sessions, however individual responses to training are likely to be markedly different (chapter 5). Therefore, it is critical that practical strategies to identify individual fluctuations in the fitness fatigue dichotomy are carried out on a daily and weekly basis (Coutts et al., 2007a, Lambert and Borresen, 2006, Twist and Highton, 2013).

The influence of the training hours experienced in the present study on fitness and fatigue needs careful consideration (Gamble, 2006). A limitation of the current study was that approximating training time could lead to inaccuracies when training time was summated across the season. However, players train for varied durations with individual and group practice pre and post training therefore measuring an exact training time for each individual was not practical. Another potential limitation was the use of the WQ to assist in individual player management. However, the player was only removed from training in an attempt to restore well-being when decreases in well-being were severe and lasted for several days or weeks. The demand of the EPPP to maximise practice time may be influencing how coaches and sport scientists manage individual players resulting in poor perceptions of well-being and physical performance.

It seems unlikely that both optimal physical performance and skill acquisition can be prioritised and it is important that coaches consider the trade-off between higher training volumes and well-being and physical performance. Higher training volumes focusing on deliberate practice may be required to optimally develop the player technically and tactically (Ericsson, 2013). However, the exposure to high training volumes may reduce well-being and physical performance (Meeusen et al., 2013). Hence, monitoring assessments which assess the responses to training may assist in the management of elite English youth players ultimately enhancing player development.

In summary, the present data gives the first insight into the potential impact of the new EPPP in England on physical performance and perceptions of well-being. Results suggest that elite youth football players in England have deteriorating perceptions of well-being, decrements in selected neuromuscular performance, but an improvement in endurance performance as the season progresses. This imbalance between high physical and psychosocial stress and subsequent inadequate recovery potentially exists as a result of high training and competition and psychosocial pressures of English elite youth football. Given that players did not actually achieve the hours stipulated by the EPPP, it would be expected that a greater training exposure would further exacerbate the imbalance between stress and recovery. Effective player management strategies need to be established to allow coaches to make informed decisions and optimise player performance. This is discussed further in section 7.1.

CHAPTER 7

General discussion

7.0 General discussion

This series of investigations was undertaken to examine the utility of subjective well-being assessments, alongside objective physical performance assessments, in the management and development of elite English youth players. In summary, the subjective well-being questionnaire designed by the sport science practitioners at a category two football club academy was sensitive to controlled acute high load compared to low load bouts of high intensity intermittent exercise and has utility in detecting acute (daily) and chronic (seasonal) training stress. The near daily completion of this questionnaire yielded varied results depending on the questionnaires temporal application. Throughout the pre-season period, which focused on high intensity, low volume training, the WQ highlighted that well-being was preserved. However, when players were exposed to greater training volumes as the season progressed deteriorations in perceptions of well-being were evident. This highlights the potential utility of these assessments in an applied setting and demonstrates an imbalance between stress and aspects of recovery in elite youth football players as the season progressed and training exposure increased and accumulated.

Responses to the well-being questionnaire, indicative of stress and aspects of recovery, can provide valuable information to assist the management and development of elite youth English players. Regardless of whether any physical performance decrements are evident, well-being is vital to the development of the player (See section 2.4.2). The imbalance between stress and aspects of recovery identified across a season in chapter six may impact on the successful development of the players and coaches with a duty of care to ensure they do all they can to manage player well-being.

As highlighted in section 2.4.2, a player with a reduction in well-being is less likely to engage optimally in the processes which are essential to the development of the player (Burgess and Naughton, 2010). Assessments of well-being are likely to give a global picture highlighting issues that may affect player development. Player well-being is multidimensional and complex. A range of stresses including training, social, lifestyle and other environmental factors can influence player well-being and the fluidity of well-being suggests it could be influenced by one or more of these factors at any point in time. Coaches and sport scientists must attempt to identify and subsequently manage factors which impair well-being and potentially have a detrimental impact on player development. The use of questionnaires such as the WQ could be a valuable tool in player management strategies if implemented correctly. For example, if the sport science practitioner's response is appropriate and the player experiences a constructive response a 'trust' develops. This facilitates honest dialogue between the player, the sport science practitioner and the coach which may help in the identification and subsequent management of these issues.

The high volume of training hours (12-14 h) stipulated by the EPPP is appears not to be conducive to maintaining a balance between stress and aspects of physical recovery on a squad level. Chapter five and chapter six indicate an impairment in aspects of neuromuscular performance (30 m sprint speed). In the pre-season period these could have been a result of a lack of an appropriate neuromuscular stimulus (Loturco et al., 2016). However, two neuromuscular training sessions were carried out per week in-season. Therefore, the lower neuromuscular performance might reflect high training volumes and be indicative of NFOR (Faude et al., 2014) or concurrent training (Loturco et al., 2015). To address these issues it seems that category one academies such as Liverpool (Malone et al., 2015b) and Wolverhampton Wanderers (Enright et al., 2015) have discarded the high training volumes proposed by the EPPP and report prescribing much lower training volumes (~5 h) throughout the in-season period. Accordingly, the current author proposes that a review of the EPPP is required in an attempt to develop a strategy which addresses the in-season deteriorations in well-being and impairment in aspects of physical performance which may be associated with high training volumes.

The imbalance between stress and recovery, indicated by an increased training exposure, a reduction in well-being and a decline in aspects of physical performance in chapter 6, could provide valuable information with regard to player management and training periodisation on a group level. Given that training is often considered on a team level, this information could be used by coaches to modify team training when necessary. However, individual case studies in chapter five highlighted that several individual confounding factors such as level of fitness (Manzi et al., 2009b), previous training history (Silva et al., 2016), genetic ceiling (Faude et al., 2014) and recovery (Bishop et al., 2008) result in individual responses to training. Given NFOR and / or a reduction in well-being is only likely to manifest itself in a few individuals (Schmikli et al., 2011), assessing players on a group level will mask individuals who might be at risk of NFOR and / or reduced well-being. Hence, clubs must design bespoke monitoring assessments which give real time feedback with regard to each individual player's response to training stress. These assessment methods must be aligned to the resources, finances and time available to sport science practitioners at each academy.

It is important to note that the present investigations did not assess football performance as a whole. The imbalance between stress and recovery observed in chapter six could have wider implications and are not limited to the physical aspects of performance. A recent media article suggested Harry Kane's poor performance at EURO 2016 was not as a result of impaired physical performance, which had been meticulously monitored by sport science staff, but instead a result of psychological fatigue (Burt, 2016). Furthermore, Ekstrand et al., (2004) highlighted that psychological fatigue was a potential factor influencing the poor performance of elite players in the 2002 World cup in players who competed in a greater number of fixtures (13 vs. 9) in the lead up to the tournament. Well-being assessments could provide insight into both the players' physical and psychological well-being and may subsequently assist in optimising player performance.

7.1 Limitations

The potential bias associated with well-being questionnaires was discussed in chapter six. The methodology used to collect the data in the present study was limited in that players may have been influenced by how other players responded to the questionnaires. The development of recent technology which is cheap and accessible would allow players to complete WQ responses in private on their smart phones which could alleviate some bias and improve compliance. If the data was collected in this manner it could be requested players fill this information in prior to 8am on the day of training and would get round any issues when players train at different venues. This would allow coaches and sport science practitioners more time and opportunity to discuss the management and modification of training if required for individual players in the daily morning meeting prior to training. Furthermore, this technology allows players to fill the subjective questionnaires in on non-training days which might give a more accurate reflection of their responses to training and match play throughout the season. However, arguably, it is the response on the day of training which is likely to impact the decision making process with regard to the management of players. .

A limitation to chapter five and chapter six was missing WQ data points in players who trained at an alternative training venue. In practice, players are often called up from the youth team to train with the development squad or first team. Hence, if the application of monitoring assessments is not seamless across the club it is difficult to effectively manage each player. Although finance, resource and logistics might dictate which monitoring assessments could be applied. An attempt must be made to implement similar metrics across the club.

The daily assessment of several objective monitoring strategies was examined within this thesis. Although HR_{rest}, and HRV were sensitive to changes in training load on a group level, the large day to day variation makes it difficult to detect changes in individuals. Hence these assessments would need to be applied on a daily basis which was not practical due to logistics and time available. Similarly, the assessment of CMJ using a contact mat was not sensitive to acute high and low load and more expensive equipment such as force plates may be required to detect neuromuscular fatigue (Gathercole et al., 2015) which were not available to the sport science practitioner in the present studies.

Submaximal HR assessments such as the HIMS applied in chapter five could not be carried out on a daily basis, again due to time constraints and the logistics of carrying out these measures. However, these assessments might yield valuable information with regard to aerobic adaptation on a weekly basis. Unfortunately, these measures are unable to give a definitive indication of positive or negative training adaptions (See section 2.6.3). Chapter five highlighted how the triangulation of submaximal HR measures, well-being assessments and the training load could be used to give an indication of how the individual is adapting to training. The positive well-being responses, decrease in HR_{ex}, increase in HRR and improvements in aspects of physical performance (aerobic fitness and CMJ) in Participant 10 give an example of how the triangulation of these methods could potentially be used to assess training responses.

The training load assessment (iTRIMP) used in chapter five was selected based on its strongest dose-response relationship with changes in aerobic fitness compared with other HR based measures (section 3.7). A limitation to any of the HR based methods assessing both training load and the training response is that they fail to quantify neuromuscular load and adaptation (Buchheit et al., 2012). Furthermore, iTRIMP is very time consuming to assess and requires regular laboratory testing which is not feasible during the in season period. Other measures such as sRPE may give a more global assessment of training load (aerobic and neuromuscular; Alexiou and Coutts, 2008) and may have been more applicable to the elite youth academy environment, based on resource, time available and immediate feedback which does not require laborious analysis. HR based methods were originally selected instead of RPE due to their stronger association with aerobic fitness (See section 2.5.5)

In an applied environment, one measure which quantifies the internal load in a single term is attractive. HR based methods may provide a valid measure of aerobic internal training load (Akubat et al., 2012, Manzi et al., 2013) but fail to quantify higher neuromuscular load (Alexiou and Coutts, 2008). A major limitation to the thesis is that player RPE was not considered in the assessment of training load. Recent studies have proposed that differential RPE (dRPE), which assesses perceptions of how hard the session was on a players legs [muscular RPE (mRPE)] and how hard the session was on a players chest [respiratory (rRPE)], could provide valuable information with regard to the balance between neuromuscular and aerobic internal demands of training and competition (See section 2.5.5).

With all monitoring assessments it is important to attempt to identify whether the change observed in a player in any given metric is meaningful. Attempts were made in chapter four and chapter five to determine the 'noise' within the assessment and what constitutes the SWC. However, the methods and statistical approach in the likely limits assessments used have their limitations. The assessment of TE is based on a group and the noise of the test in each individual will differ to a varying extent

(Buchheit, 2014). Furthermore, establishing the TE for each of these assessments is not practical due to time constraints. Taking a week to establish the reliability of these assessments is impractical in elite youth football players, hence, the approach of using a similar age matched population to determine the reliability of assessments in this thesis. In addition, determining the TE of maximal performance tests is even more challenging as it difficult to establish the day-day variation due to the fatiguing nature of these tests. However, in an applied environment, sport science practitioners must attempt to acknowledge the uncertainty in the measure when making inferences about changes in physical performance (Hopkins, 2004).

Another limitation to the likely limits approach proposed by Hopkins to assess athletes is how the SWC is determined. The use of 0.25 of the between player SD is influenced by group homogeneity (Buchheit, 2016). Hence, the introduction of three slower players into the squad would increase the arbitrarily derived SWC value which may not translate to practically important performance change. A more worthwhile approach would be to identify what constitutes a meaningful change in a game situation. For example, getting to the ball 20 cm ahead of an opposing player is required to regain possession of the ball. Hence a 1 % improvement in sprint time (e.g. ~0.04 s in a 30 m sprint) would constitute a meaningful change (Buchheit, 2016). Determining the SWC in assessments which do not have a direct link to performance such as submaximal HR assessments is more challenging. Buchheit (2016) suggested the use of 0.2 within player variation could be used to identify whether a change was evident. However, as previously noted, the direction of this change would need to be considered in relation to other measures such as the training load and perceptions of well-being to ascertain the training response.

7.2 Practical applications

The conceptual researcher practitioner model highlights how sport science practice and research can be embedded to support to coaches and players and improve the management of elite youth football players (Coutts, 2016; Figure 7.1). The concept of 'working fast' and 'working slow' identifies the need for an integrated approach to practice and research (Coutts, 2016; McCall et al., 2016). 'Working fast' is critical for the sport science practitioner to allow them to make immediate decisions, on a daily basis, which have a direct application to training periodisation and the management of players (McCall et al., 2016). The 'fast working' sport science practitioner collates data from range of physical performance and well-being assessments and is often required to make immediate decisions based the data available to them and their intuition. However, this data is often not subjected to the level of scrutiny a researcher would expect due to time constraints and / or a lack of expertise (McCall et al., 2016). The concept of 'working slow' refers to the researcher working behind the scenes to provide an evidence base for well-being and performance assessments. This often involves working retrospectively with large data sets to ensure the validity of assessments and establish the noise and SWC for individual players. Hence, the conceptual researcher practitioner model highlights the potential to improve the management of elite youth football players through the integration of applied practice and research.

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Figure 7.1 The conceptual researcher practitioner model (Coutts, 2016).

The research in this thesis was embedded into applied practice at the Category 2 academy. On reflection this process assisted in the development of an evidence based approach to managing elite youth football players. However, the research was carried out by the sport science practitioner. This led to many challenges and conflicts with regard to applied practice and research. Time spent analysing data retrospectively ('working slow') could have spent working with the players on field or in the gym to improve them. Very few academies seem to invest resources into research (Enright et al. 2015; Malone et al. 2015b). Therefore it is suggested the EPPP should encourage academies to collaborate with universities and embed 'slow working' researchers into academies to work with sport science practitioners to further enhance and develop sport science support for elite youth football players.

The complexities of using monitoring assessments is challenging to the sport science practitioner. A key consideration to sport science practitioners must be what metrics they identify as being important to player management which can be implemented within the constraints (e.g. time, resource and logistics) they must operate. Often sport science practitioners are compelled to collect high volumes of data using a multitude of metrics. Much of this data may be useful in retrospective analysis if time permits ('working slow') but is unlikely to influence the immediate real time management of players ('working fast'). Sport science practitioners are constantly attempting to address the balance between art and science when applying monitoring assessments to ensure athlete well-being and maximise football performance. A single measure alone is unable to give a definitive prediction of how a player will perform at any point in time and coaches and sport science practitioners need to use their experience and intuition to interpret the data in conjunction with any other relevant information available to them.

Chapter five and chapter six highlights the need for a mixed methods monitoring approach. For example, maximal performance tests may have limited applicability in that they only give a snap shot of where that player is at that point. Therefore, although these performance assessments can give a valuable insight into the effectiveness of the training programme over a short term period they cannot be used to manage players on a daily basis. Another issue with maximal performance tests is, as a sport science practitioner, it is challenging to negotiate with the coach regarding when these tests fit into the training and competition schedule. In the present study performance tests were performed ~48 h following a game. Therefore, the testing results might reflect acute responses to training and competition rather than longer term adaptations. Greater direction should be provided in the EPPP with regard to the scheduling of maximal performance tests. Giving the players four days to recover prior to the application of the tests would give a more accurate reflection of how the player is adapting (Krustrup et al., 2011). Furthermore, four days recovery following the tests would allow players to recover adequately. The addition of testing / recovery weeks might provide valuable intermissions during the season preventing the imbalance between stress and recovery observed as the season progresses.

'Working fast' puts an emphasis on data collection which must contribute to answering relevant questions which enable the sport science practitioner and coach to evaluate and modify the training program for each individual player. For example the data must be used to ascertain 'Is the player ready to train today? Or 'is there an imbalance in the players training load?' A rolling average of well-being responses used in chapter six and the tracking of these measures over time could highlight a 'red flag' if an individual was below baseline which could assist in modifying a players training or inform an appropriate lifestyle intervention. However, it may be difficult to determine a threshold where a players training should be modified. The incorporation of science and art where a 'red flag' elicits a discussion between the player, sport science practitioner and the coach which influences the subsequent management of the player might be the most effective approach. Given many aspects of football performance are intangible, ultimately, an athlete's perceptions of well-being and the 'coach's eye' or intuition could be the most valuable tool available to manage the development of elite youth football players.

Anecdotally, the implementation of well-being assessments at the club in question improved the sport science practitioner's and coach's awareness of player well-being. The WQ responses elicited many discussions with the coach and sport science practitioner. The coach was often reluctant to reduce the players training volume due to the importance of deliberate practice hours. However, the training volumes on a group level were lower than those stipulated by the EPPP (9.6 h vs. 12-14 h, chapter six) which was influenced by the players' well-being responses and discussions between the sport science practitioner and the coach. Furthermore, in two instances players had their training modified when a severe decrease in perceptions of well-being was evident. This highlights the operational use of subjective well-being questionnaires on a daily basis in an applied setting.

As previously noted, the successful implementation of well-being assessments is dependent on several design and environmental factors (section 2.5.1). Coach buy in is an important aspect. If players feel they will be branded as 'weak' or 'soft' it is likely to influence their responses. The sport science practitioner must educate the coach on the importance of these responses and develop a relationship in which players do not feel ostracised. The coach did not look at any of the WQ responses in the present studies and was only consulted by the sport science practitioner when they felt an intervention was needed. It was felt that this approach would strengthen the relationship between the sport science practitioner and the player enhancing the ability to gain a valid assessment of the players' well-being. This linked into educating the players on the value of these responses which were designed to assist in their management and development and the ultimate goal of becoming a professional football player. Interestingly the coach often enquired about a player's WQ responses if he noticed an issue with a player. Even in the absence of any change in WQ responses the coaches intuition would again act as a 'red flag' and prompt a discussion between the player, coach and sport science practitioner. This highlights the importance of integrating science and art, using all the information available to manage player well-being.

Well-being assessments alone may be unable to dichotomise between the multifactorial stresses (e.g. training and match load, social or environmental) which influence well-being responses. The key aim of these responses should be to identify 'red flags' which encourage dialogue between the sport science practitioner and the player. The sport science practitioner must have the soft skills to unpick what the issue might be and act as a filter to subsequently manage these issues with other members of the interdisciplinary team (e.g. coach, academy manager, education officer, welfare officer, physiotherapist). It is proposed that this player centred approach would enhance the development of elite English youth players.

The WQ was designed based on items which were sensitive to changes in training load (See section 2.5.1). However, additional items such as 'enjoyment' 'social stress' or 'well-being' may provide a more holistic picture of player well-being. Identifying which questionnaire items are most valuable in the management of elite English youth football player is important. A balance between the number of questions asked and gaining relevant information is challenging. If the questionnaire is too long player compliance will be reduced. Therefore, identifying which items are most useful in developing dialogue with each player is important. Even a simple question 'how do you feel today?' might be enough to assist in player management. A key aspect to consider is each players understanding of each questionnaire item. Attempts were made to educate players on the meaning of the questionnaire items which should have in part alleviated any of these potential issues (Appendix 5). An important aspect in the practical application of questionnaires designed 'in-house' is the players must have a good understanding of what each questionnaire item is assessing.

In summary, well-being assessments could be the most promising standalone assessment to assist coaches and sport science practitioners in the management of elite youth players. The triangulation of objective measures, subjective well-being assessments and the 'coach's eye' can provide a practical strategy to monitor the well-being, football performance and development of elite English youth football players. These assessments must be considered on an individual level to account for idiosyncratic responses.

7.3 Further research

The findings reported in this thesis raise further research questions regarding the development of monitoring assessments to assist in the management of elite youth football players. Although the present thesis supports the use of 'in-house' well-being questionnaires to assist in the management of elite youth football players, further investigation is required to develop such monitoring assessments. The integration of subjective assessments with objective monitoring assessments has been discussed and proposed, however the determination of thresholds which indicate a negative or positive training response for each individual and allow subsequent intervention require further development. To advance the validity of monitoring assessments, used to inform well-being and performance management of elite youth football players, the following types of investigation are recommended: i) the exploration of other questionnaire items which might be of interest to the sport science practitioners working with elite youth football players (e.g. enjoyment, social stress); ii) investigate the relationship between player well-being and football performance (technical, tactical, physical and psychological); iii) apply within-participant case study designs to develop an approach to monitoring which determines individual thresholds indicative of a negative training response.

The present thesis proposed and discussed seven questionnaire items (motivation, sleep quality, recovery, appetite, stress, fatigue and muscle soreness) which could be applied to assess stress and aspects of recovery in elite youth football players. Additional items could further enhance the dialogue between player and sport science practitioner encapsulating a more holistic depiction of stress and aspects of recovery. Further research involving focus groups with elite youth players could elucidate which questionnaire items are most relevant to the stresses elite English youth players are subjected to.

As highlighted in section 7.1, a reduction in player well-being may not impact on physical performance, but could influence football performance. One of the most interesting aspects of player well-being could be the relationship between player well-being and performance as a whole. Identifying whether perceptions of well-being influence match performance throughout the season would indicate the usefulness of well-being assessments as a performance management tool in elite youth football players. The assessment of player well-being, in addition to coach perceptions of player performance and the quantification of match performance using a battery of KPIs could provide a valuable insight into well-being and performance in elite youth football players.

The applied nature of the work in the present thesis highlights the need for a greater consideration of individual responses. An approach which considers within-participant case study designs, in which the 'noise' of the assessment for each individual and the SWC are considered, are required to ascertain a threshold which constitutes a meaningful change. Investigating the triangulation of a range of objective assessments (e.g. performance, biochemical, immunological) and subjective assessments, using within-participant case study designs longitudinally, could highlight the effective application of monitoring assessments applied to assist in the management of elite youth football players.

7.4 Conclusion

To conclude, this thesis provides evidence to support the use of well-being questionnaires developed 'in-house' to detect training stress in elite youth football players. The temporal application of well-being assessments in addition to performance assessments on an individual level could assist in the management elite English youth football players subsequently enhancing player development.

Furthermore, the high training volumes English elite youth players are exposed to may result in an imbalance between stress and recovery.

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APPENDIX 1. Participant Information

Participant / Parent Information Sheet

Study Title

Assessing training load, fitness and fatigue.

Study Invitation

You have been invited to take part in a research study. Before you agree to take part it is important you read through this information sheet so that you understand what the study will involve and whether you wish to take part. If anything is unclear, make sure you ask.

What do I have to do?

<u>Part 1</u>

- Performance / fatigue tests on 5 consecutive days during your half term training camp.
    - This will include:
        - Questionnaires.
        - Jump tests, resting heart rate test and a low intensity shuttle run.
- You must also fill in a diary about your training throughout the 5 days.
- Prior to any testing it is that requested you:
    - Rest between testing and sessions and undertake no additional training.

    - Try not to carry out weight sessions. If you must limit it to upper body sessions.
    - Prepare for the tests in the same way each day
        - Eat a similar breakfast at the same time (1-2 h before).
        - Take on enough fluids (Do not drink large volumes in the hour prior to the testing).
        - Do not take any caffeine on the morning of the tests.
        - Bring the same appropriate trainers with you each day (we will be in the sports hall).

<u>Part 2</u>

- You will be required to take part in a high load (hard) and a low load (easy) training session on 3 occasions.
- You will perform the Performance / fatigue tests the morning following the training session.
- All training sessions the week before will be monitored with Heart Rate and GPS.

How much time will it take?

All the testing will be integrated into your training, training camps and college timetable. No testing outside of this will be required.

Are there any risks in taking part?

You will be at no increased risk to injury taking part in the study.

How will I benefit from taking part?

Information about your performance / fatigue levels may help coaches plan your training more effectively.

Will I get any payment or expenses for taking part?

No payment or expenses will be paid for taking part in the study.

What will happen to my data?

All data will be kept confidential and the researcher will ensure individuals cannot be identified. You will have access to all your own data if you wish.

What happens if I don’t want to continue with the study?

You are free to withdraw from the study at any point. If requested all your data will be deleted and not used in the study.

What if there is a problem?

If you have any issues you can contact the lead researcher, Mark Noon (mob. 07585606849, email. mrnoon@aol.com). If you have any questions about your rights or feel you have been placed at risk please contact Dr. Doug Thake (email. d.thake@coventry.ac.uk).

APPENDIX 2. Participant information and informed consent

INFORMED CONSENT FORM

FOR STUDENT PROJECTS AND STUDENT PLACEMENTS IN THE DEPARTMENT OF BIOMOLECULAR AND SPORT SCIENCES COVENTRY UNIVERSITY

.**NAME OF STUDENT** Mark Noon

NAME OF UNIVERSITY SUPERVISOR Dr. Doug Thake

COURSE TITLE Ph.D in physiology

TITLE OF RESEARCH PROJECT

Assessing training load, fitness and fatigue in elite soccer players

Thank you for agreeing to help one of our students with their research work. This form explains what you will be asked to do. If you have any questions about this please ask the student.

By signing this form you agree to take part in the study. However, please note that you are free to stop taking part at any time.

PURPOSE OF THE RESEARCH

The purpose of this research is to enhance the planning of training through monitoring the influence of training on fitness, fatigue and injury.

PARTICIPATION IN THIS RESEARCH WILL INVOLVE

In taking part in this study you will be asked to confirm your gender, age and if you are able to participate in physical activity. Prior to training each day the subject will fill out a Recovery Questionnaire comprising of 7 questions covering, motivation, sleep quality, level of recovery, appetite, fatigue, stress and muscle soreness. The questionnaire takes approximately 30 seconds to complete and score their answers on a Likert scale ranging from -3 (very poor) to 3 (very good). Participants will also be required to wear a heart rate monitor during all on pitch training sessions to quantify the internal physiological training load and at times a GPS vest to quantify external load. After each training sessions participants will be asked to provide a rating of intensity for each session on a scale of 1-10 (1 being the lightest, 10 being the hardest).

Once a week you will need to give a saliva sample and carry out a sub maximal 12 min test before training. The submaximal test involves 4 x 2 min runs with 1 minute in between at a low intensity over 20m distances. Saliva will be collected in a small tube in the morning before training. You will be asked to place an oral swab under the tongue on the base of your mouth for 5 minutes.

You will be required to take part in your normal testing protocols 6 times a season. These tests include a laboratory treadmill test, sprint tests, jump tests, yo-yo test and gym based strength tests that you are familiar with.

FORESEEABLE RISKS OR DISCOMFORTS

The heart rate monitor strap may irritate the skin, this risk can be minimised by washing the heart rate monitor strap after each training session. You will not be required to perform any additional physical activity other than what is prescribed to them by the coaching staff at Coventry City Football Club academy.

BENEFITS TO THE SUBJECT OF PARTICIPATION

This work will provide a monitoring tool to aid optimal physical development. The range of data collected will allow individual player monitoring which can be used to monitor fitness and fatigue and therefore influence subsequent training, strength and conditioning and recovery strategies.

WHAT WILL HAPPEN TO YOUR DATA

Any data/ results from your participation in the study will be used by Mark Noon as part of their project work. The data will also be available to Dr Doug Thake and Mr Mark Noon. This piece of work may also be published in scientific works, but your name or identity will not be revealed. If you wish to attend a debrief at the end of the study to discuss your data and how it was used this can be arranged with the researcher.

All data will be kept confidential and the 1998 Data Protection Act will be strictly adhered to ensure your rights are protected.

Subject codes will be used for data that is stored electronically to ensure individuals cannot be identified. At the start of the testing period you will be assigned an identification number for them to use when filling in questionnaires. Details of each individual's identification number will be kept on a separate sheet of paper and kept away from files with data of the participants on.

If you have any questions or queries Mark Noon will be happy to answer them. If they cannot help you can contact Dr. Doug Thake on d.thake@coventry.ac.uk.

Mark Noon – 07585606849 or MRNoon@aol.com

If you have any questions about your rights or feel you have been placed at risk you can contact Dr. Doug Thake.

I confirm that I have read the above information. The nature, demands and risks of the project have been explained to me.

I have been informed that there will be no benefits/ payments to me for participation

I knowingly assume the risks involved and understand that I may withdraw my consent and discontinue participation at any time without penalty and without having to give any reason.

Subject's signature __________________________________Date _____________

Investigator's signature ______________________________Date _____________

Signature of Parent/ Guardian _________________________ Date _____________

The signed copy of this form is retained by the student and at the end of the project passed on to the supervisor. A second copy of the consent form should given to the subject for them to keep for their own reference.

APPENDIX 3. Well-being Questionnaire (WQ)

	Very Good		Good	Normal	Poor		Very Poor
Level of motivation to train	3	2	1	0	-1	-2	-3
Quality of sleep	3	2	1	0	-1	-2	-3
Level of recovery from previous day	3	2	1	0	-1	-2	-3
Level of appetite (High=VG, Low=VP)	3	2	1	0	-1	-2	-3
Feelings of fatigue	3	2	1	0	-1	-2	-3
Feelings of stress	3	2	1	0	-1	-2	-3
Muscle soreness (Not Sore=VG, Sore-VP)	3	2	1	0	-1	-2	-3

APPENDIX 4. Well-being Questionnaire (WQ) definitions

Level of motivation to train Do you feel motivated and up for training today?
Quality of sleep Did you sleep well last night? Was your sleep undisturbed? Did you sleep without waking?
Level of recovery from previous day How recovered do you feel from yesterday?
Level of appetite (High appetite=Very Good , Low appetite=Very Poor) Have you felt hungry over the past 24 h. If you are not very hungry or eating enough this may contribute to under recovery
Feelings of fatigue How fatigued / tired do you feel? What are you energy levels like?
Feelings of stress Do you feel stressed or anxious about anything? Is there anything worrying you?
Muscle soreness (Not Sore=Very Good, Sore-Very Poor) Do your muscles ache and feel tight?

APPENDIX 5. Activity diary

Date……………………………………………………………………………………….

Name……………………………………………………………………………………

1) How hard did you find yesterday's testing and technical sessions? (RPE Score 1-10)

1 2 3 4 5 6 7 8 9 10

2) Did you carry out any other physical activity yesterday?

Yes / No

3) If yes what activity did you carry out (e.g. gym, extra conditioning, kick around with mates)?

……

……

4) How long did each of these activities last?

……

……

5) How hard did you find these additional sessions? Score each activity (RPE Score 1-10)

……

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